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PRINCIPLES
OF
OIL AND GAS PRODUCTION

BY

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PREFACE

In preparing this work the authors' aim has been to fill the need for a general treatise on the production of oil and gas, since the books on the subject are too brief, out-of-date, inapplicable to American conditions or treat only a small part of the field. We are fully conscious that conditions differ widely, the world over, in the productive oil and gas fields. We have, therefore, limited ourselves to a discussion of the subject with reference chiefly to American conditions.

Yet to treat in a well-balanced way all the multifarious subjects that might be included under the head of Oil and Gas Production would exceed the space we have allowed ourselves. Indeed, it is doubtful if any author in such a broad field can write a well-balanced book, since one aspect or another is sure to claim his especial attention. We have tried to treat more fully the newer, less developed topics and less fully those that have a literature, citations to which are given. For a fuller treatment of the chemistry and origin of petroleum the reader is referred to Bacon and Hamor's "The American Petroleum Industry." For the drilling of wells, we have Paine and Stroud's "Oil Production Methods."

To some the drilling of wells may seem the very heart of oil and gas production, but it is in fact merely an operation used also by the miner and the prospector for water, and is not worthy of the disproportionate attention it has received, as compared with that given to the very vital need of developing better methods of locating and extracting.

Since certain chapters will doubtless be read by those who may not read the whole book, we have permitted ourselves some repetition, in order that each chapter may offer more adequate treatment of its subject.

The reader will soon discover that this book represents a reaction from the undue emphasis on the attitude of the beds, as seen in the general literature of oil geology, to a fuller consideration of the shape and texture of the reservoir itself. We feel that the time is past when the sole requirement of an oil geologist is his ability to recognize and map folds.

ROSWELL H. JOHNSON.
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University of Pittsburg.
Dec. 21, 1915.

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PRINCIPLES OF OIL AND GAS PRODUCTION

CHAPTER I

VARIETIES OF OIL AND GAS

Oil. — Petroleum consists mainly of a mixture of liquid hydrocarbons, which are members of a series varying from substances which are solid at ordinary temperatures to the lightest gases. Chemically these hydrocarbons exist in one of several regular series, as follows:

Generalized formula.	Name of series.	Most abundant in oil from
C_nH_{2n+2}	Paraffin	Pennsylvania and in natural gas
C_nH_{2n}	Olefin and polymethylene	Russia, California and Cuba
C_nH_{2n-2}	Acetylene	Texas, Louisiana and Lima-Indiana
C_nH_{2n-4}	Rare	Lima-Indiana and California
C_nH_{2n-6}	Benzene	Nearly all fields in small quantities
C_nH_{2n-8}	Rare	California
C_nH_{2n-10}	Rare	
C_nH_{2n-12}	Includes naphthalene $C_{10}H_8$	California and Cuba

Each of these series has many members.[1] The following list of the lower members of the paraffin series will suffice to show the typical change in physical characteristics.

Name.	Chemical symbol.	Boiling point F.	Gravity B. at 68° F.	Commercial name.
Methane	CH_4	−256.5°		Natural Gas
Ethane	C_2H_6	−135.4°		
Propane	C_3H_8	− 49.0°		Gasol
Butane	C_4H_{10}	+ 33.8°		
Pentane	C_5H_{12}	+100.4	93° at 57°	Gasoline
Hexane	C_6H_{14}	+158.0	83°	
Heptane	C_7H_{16}	+208.4	75°	
Octane	C_8H_{18}	+257.0	69°	
Nonane	C_9H_{20}	+298.3	65°	Kerosene
Decane	$C_{10}H_{22}$	+334.3	62°	

There are in addition in lesser amounts compounds of carbon and hydrogen with nitrogen,[2] oxygen and sulphur. The compounds with oxygen or sulphur when solid or semi-solid are called asphalt.

---

[1] Clarke, F. W., U. S. Geol. Sur. Bull. 616, pp. 713–737.

[2] Mabery, C. F. Relations of the Chemical Composition of Petroleum to its Genesis and Geologic Occurrence.

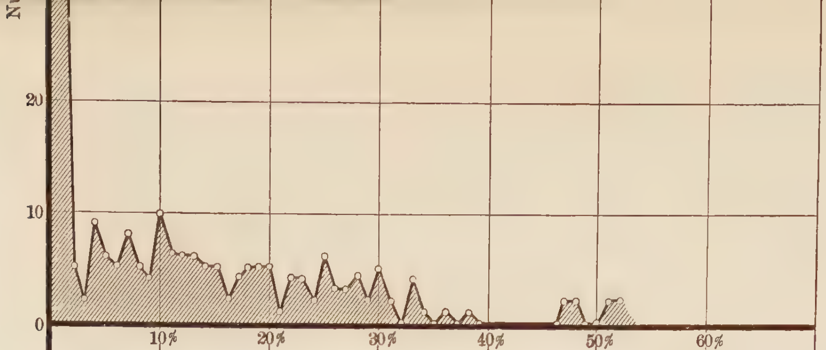
Natural gas consists principally of the lightest of the paraffin series (methane, CH_4) usually mixed with varying amounts of other gases and volatile hydrocarbons. The former consist of small amounts of carbon dioxide (CO_2), nitrogen and in some districts considerable hydrogen sulphide (H_2S). Traces of oxygen are frequently reported, but some authorities are inclined to believe that this is due to air which is included with the sample. However, the proportion reported as nitrogen occasionally contains as well small amounts of one or more of the rare gases helium or argon.

Casing-head gas, coming from oil wells or associated with the oil in the immediate vicinity of such wells, frequently contains considerable amounts of ethane, propane and butane. The last two of these compose part of the condensate in the extraction of gasoline from such gases by compression. However, their boiling points are so low that the expense of condensing these lighter gases is disproportionately high, and their condensate is so unstable at ordinary temperatures as to make the waste through evaporation excessive and add to the danger of handling and using it. This is also true in a greater degree of methane, which requires a temperature of $-160°$ C. ($-256°$ F.) to prevent volatilization at atmospheric pressure.

Relatively low-grade naphtha containing still heavier hydrocarbons is blended with gas-gasoline to produce a commercial gasoline of the same gravity as ordinary refinery gasoline, but containing varying proportions of the lighter compounds to compensate for the heavier naphtha.

In Figs. 1–6, 7–11 and 14–15, showing the composition of the oils of the United States, the analyses are those given in the U. S. Mineral Resources for 1913. While some pools are over-represented and others unrepresented, the general shape of the curve probably differs but little from a curve made from the result of an analysis from each pool or for each unit of quantity.

The price of crude petroleum in the United States is not based solely upon the relative proportion of its products (Figs. 1–6), but also upon the cost of transportation to refineries and thence to the ultimate consumer. Cushing oil sold at $0.40 a barrel while Pennsylvania grade sold at $1.35, although the difference in the intrinsic value of their products is much less than this. Mr. Harry Willock, Secretary of the Waverly Oil Works, made the following report to the Oklahoma Corporation Commission, as to these relative values. He states, "As nearly as I could figure, the value of the products from Pennsylvania and Cushing crude, based on the comparative run made by the Wells Refining Oil Process Company, would be as follows:



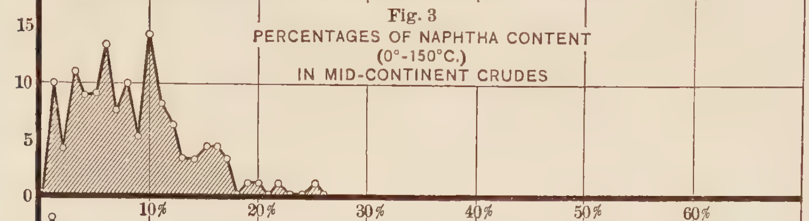


Fig. 3
PERCENTAGES OF NAPHTHA CONTENT
(0°-150°C.)
IN MID-CONTINENT CRUDES

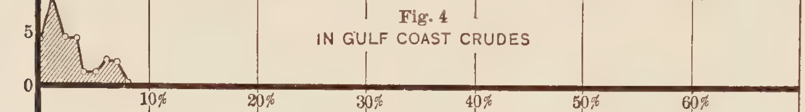


Fig. 4
IN GULF COAST CRUDES

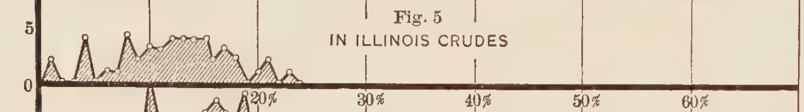


Fig. 5
IN ILLINOIS CRUDES

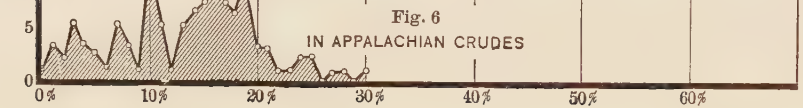


Fig. 6
IN APPALACHIAN CRUDES

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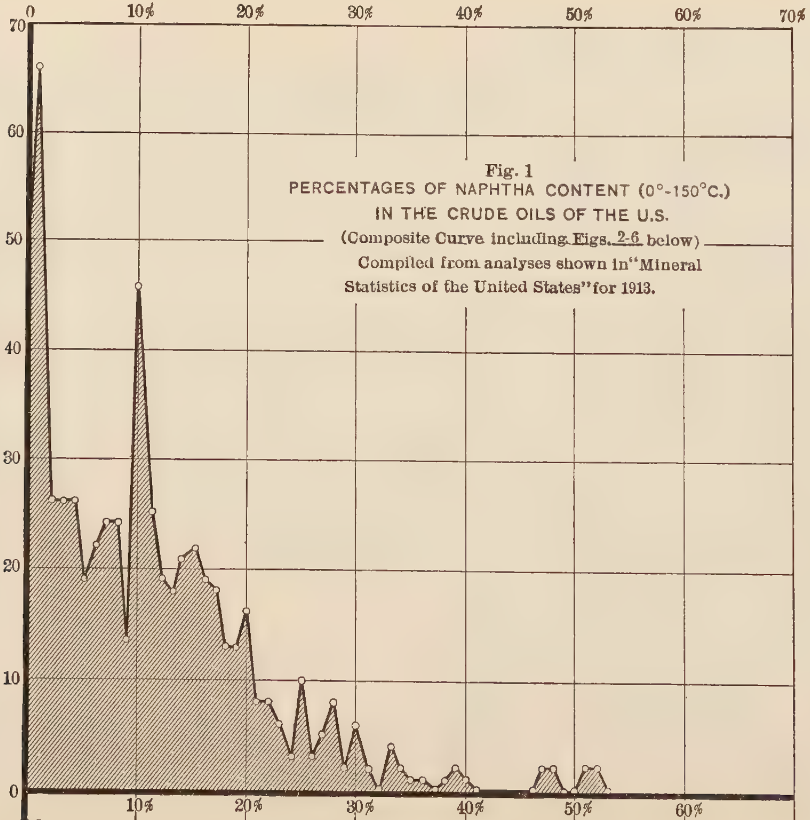

Fig. 1
PERCENTAGES OF NAPHTHA CONTENT (0°-150°C.)
IN THE CRUDE OILS OF THE U.S.
(Composite Curve including Figs. 2-6 below)
Compiled from analyses shown in "Mineral
Statistics of the United States" for 1913.

PENNSYLVANIA CRUDE

Fraction.	Gravity.		Value.
	°B.		
Gasoline (36 per cent)	66.2	25 gal. @ $0.12	$3.00
Turp. subt.	51.9	15 “ “ 0.085	1.28
Kerosene	45.7	15 “ “ 0.05	0.75
300 oil	40.3	15 “ “ 0.05	0.75
Non. vis. neut.	35.5	12 “ “ 0.045	0.54
Vis. neut.	31.0	8 “ “ 0.12	0.96
S. R. cyl. stock	25.0	8 “ “ 0.12	0.96
Ref. parf. wax		2 “ “ 0.25	0.50
Total		100 gal.	$8.74
5 per cent gallonage loss in manufacture			0.44
Total value of products			$8.30

CUSHING CRUDE FROM OKLAHOMA

Fraction.	Gravity.		Value.
	°B.		
Gasoline (48 per cent)	65.7	30 gal. @ $0.12	$3.60
Turp. subt.	48.2	20 “ “ 0.085	1.70
Kerosene	40.1	15 “ “ 0.03	0.45
Gas oil	34.6	15 “ “ 0.02	0.30
Vis. neut.	28	10 “ “ 0.10	1.00
S. R. cyl. stock	24	6 “ “ 0.08	0.48
Ref. parf. wax	0.5	0.5 “ “ 0.25	0.13
Asphalt		3.5 “ “ 0.06	0.21
Total		100.0 gal.	$7.87
5 per cent gallonage loss in manufacture			0.39
Total value of products			$7.48

“You will note from the above figures that the products from 100 gallons of Pennsylvania oil only exceed in value the products of a like number of gallons of Cushing crude by $0.82, or in other words, that Pennsylvania oil from a refining standpoint is worth approximately 10 per cent more than Cushing oil; although at the present time with Cushing oil selling at $1.20 and Pennsylvania oil at $2.15 at the wells, the price of Pennsylvania oil is nearly two times that of Cushing.”

Gravity. — A rough basis of classification frequently used is that based upon the specific gravities of crude oils, which is correlated in a general way with the percentage of the more valuable light oils present in the crude petroleum. However, this classification cannot be relied upon, because in the case of the heavier crudes we have a comparatively new competition with coal as a fuel. This led to the anomalous condition existing recently of a high-grade oil (Cushing) being sold at a less price for refining purposes than that which prevailed for Cali-

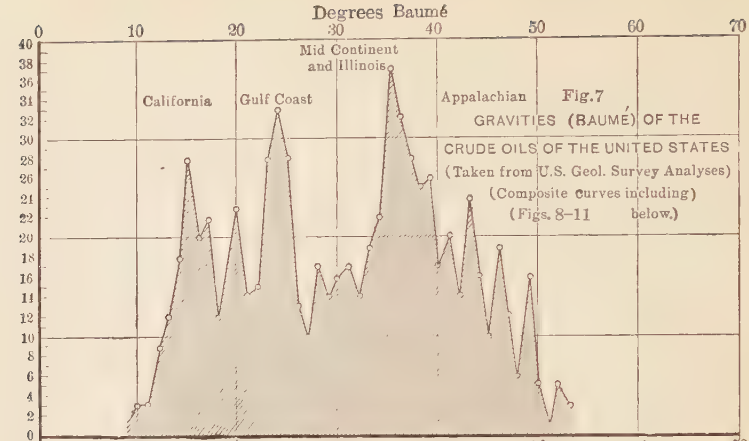

Fig. 7
GRAVITIES (BAUMÉ) OF THE
CRUDE OILS OF THE UNITED STATES
(Taken from U.S. Geol. Survey Analyses)
(Composite curves including)
(Figs. 8–11 below.)

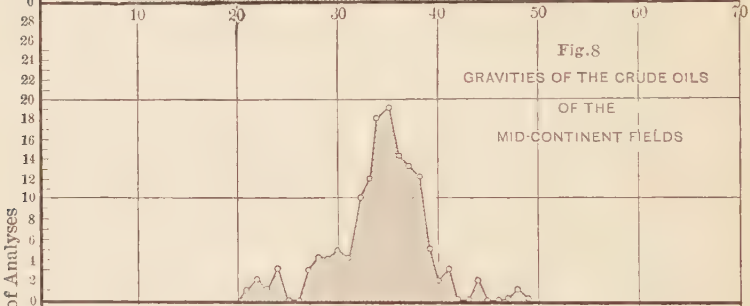

Fig. 8
GRAVITIES OF THE CRUDE OILS
OF THE
MID-CONTINENT FIELDS

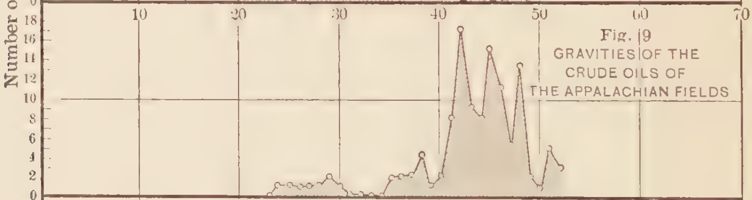

Fig. 9
GRAVITIES OF THE
CRUDE OILS OF
THE APPALACHIAN FIELDS

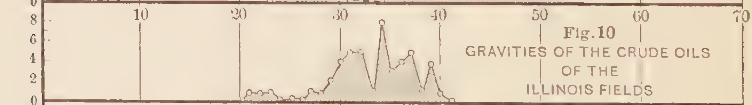

Fig. 10
GRAVITIES OF THE CRUDE OILS
OF THE
ILLINOIS FIELDS

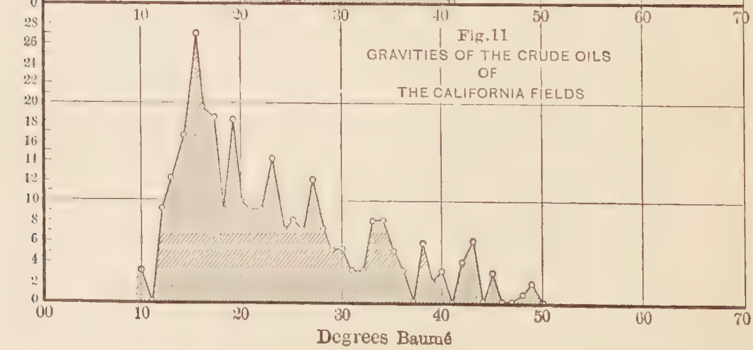

Fig. 11
GRAVITIES OF THE CRUDE OILS
OF
THE CALIFORNIA FIELDS

fornia and Mexican fuel oils in the United States. Conditions such as this are inherent in the oil business, when the sudden development of large pools gluts the market, and leads to the utilization of an economically high-grade material for inferior uses. (Fig. 12.)

Figs. 7–11 show the range of the gravities of the crude petroleums of this country. It will be noticed that in general these arrange themselves into two general types — one from 12° to 25° B. predominating in the California and Gulf Coast fields, and the other from 32° to 48° B. predominating in the Mid-Continent, Illinois and Appalachian fields. There is a relative scarcity of intermediate oils, from 27° to 32° B., as well as of those of very high gravity, represented by Pennsylvania crude (44° B.).

Heating value. — Many of the heavy "fuel" oils contain a certain percentage of light hydrocarbons, frequently enough so that it pays to "top" them, that is, to run them through the first step in the distillation process in order to extract the relatively high-priced gasoline content before the bulk is sold as fuel oil. Even in the higher grade petroleums, after the distillation is carried further, the residue is sold as fuel oil. This is done in Oklahoma, Wyoming and elsewhere in this country, as well as in Russia and Roumania. While improved processes for refining these heavy oils have been installed in a number of the large refineries, notably those at Whiting, Indiana, Neodesha, Kan., Port Arthur, Tex., yet the heavier expense has restricted their introduction during the recent period of low prices. Meanwhile the use of heavy crude oil and residues for fuel in steam plants, railways and for marine purposes increased rapidly with improved burners and methods. At the same time the adaptation of the internal combustion engine of the Diesel type using crude oils has greatly increased the efficiency of this form of fuel. The change from coal-burning to oil-burning equipment has been somewhat delayed by the fear that the rapidly increased consumption of refined products and the adaptation of improved refining methods of transforming heavy oils, combined with the falling off of the production of oil, would so advance the price of fuel oil that before such equipment had worn out it could no longer be used. However, the development of the Mexican oil fields has given assurance of a constantly increasing supply of fuel oil for a number of years to come, and at the end of the European conflict we shall doubtless see a great expansion in the use of fuel oil for power purposes, particularly at seaboard points and for marine uses.

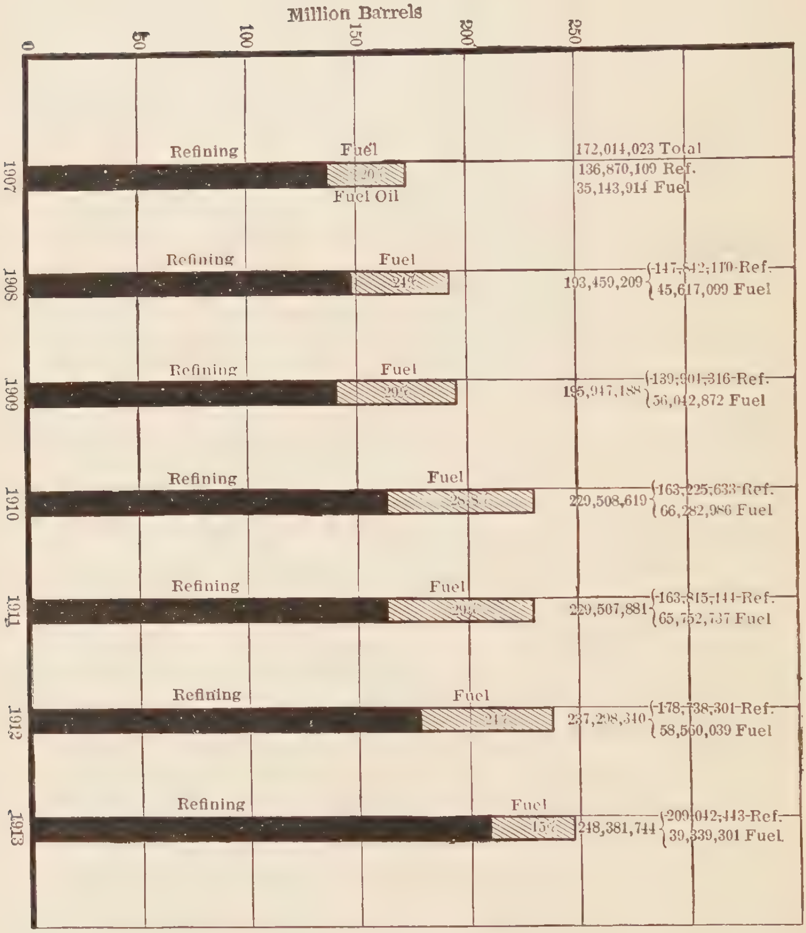

FIG. 12. Diagram showing the increasing proportion of crude oil which is subjected to refining, in spite of the large increase in the use of fuel oil.

The following table shows the relative heating value of various representative fuel oils, as compared with typical steaming coals:

Crude petroleum.	British thermal units.	Coal.	British thermal units.
Average 6 samples Cushing crude	19,755	English	14,112
Average 5 samples Boston pool, Oklahoma	19,661	Connellsville	14,580
Average of crudes from 30 Oklahoma pools	19,567	Pennsylvania anthracite	15,700
Pennsylvania heavy crude	20,736	Pocahontas	15,740
Caucasian light	22,027	Kentucky (average)	14,100
Caucasian heavy	20,138	Texas "	13,670
Petroleum refuse	19,832	Indiana "	12,420
Average fuel oil	18,900	Illinois	11,160
Mexican fuel oil (Panuco?)	18,000	Missouri	11,500
California fuel oil	18,630	Wyoming	10,200
Gulf coast fuel oil	19,028	Colorado	12,840
Caddo, Louisiana	19,163	Typical western lignite	10,426
Lima-Indiana field	18,900	Mexican	11,500
Austrian and Russian petroleum residues	18,900	Average British	13,968
		Good steaming coal used by the U. S. Navy	13,500

The United States Bureau of Mines (Technical Paper 37) shows the following relation between coal and oil as a fuel for steaming purposes:

1 ton (2000 pounds) steaming coal requires 40 cubic feet of storage space
1 ton fuel oil requires 35 cubic feet of storage space
} Ratio 10 : 11.5

Good steaming coal develops 13,500 B.T.U. per pound
Average fuel oil develops 18,900 B.T.U. per pound
} Ratio 10 : 14

Therefore for marine purposes, considering storage capacity and relative calorific values, coal bears the relation to oil of 10 : 16.1. The United States Navy tests show even a higher value (10 : 17).

The following table shows the prices at which fuel oil would still compete with various steaming coals:

Coal.	B.T.U.	Cost per ton.	Price at which fuel oil would still compete.
Good steaming coal	....	$8.20	$2.00 per barrel (42 gal.)
Mexican coal	11,500	4.13	1.35 Stationary (marine)
Lehigh coal	....	3.45	1.30 U. S. railway tests.
Lehigh Slack	....	3.25	1.72
Wilburton coal (screened lump)	....	3.60	1.21
McAllister Mine run coal	....	3.50	1.16
Oklahoma coal	....	1.90	0.80 Test runs on the A. T. & S. F. between Kansas City and Newton
Good steaming coal	....	3.00	2.98 Marine

NOTE. — The last two examples were calculated on a basis including the excess earning capacity of vessels, after the installation of oil-burning equipment, by devoting the space saved in fuel storage to cargo; and also includes the saving in payroll and general expenses, as shown in the examples given below.

The other examples shown above are arrived at by dividing the saving in cost per ton mile, or per horse-power (as the case may be), by the number of barrels used, as shown in Example III, following.

Example I. — Taken from figures given in "Mexican Fuel Oil," published by the Anglo-Mexican Petroleum Products Co., showing the savings effected in two round trip voyages of a vessel from Trieste to Buenos Aires, using coal and fuel oil:

Used 7175 tons of coal per round trip at $8.20 per ton (2000 pounds).
Used 4683 tons of oil per round trip at $11.61 per ton (2000 pounds).

Saving in cost of fuel, plus decreased expenses (crew and supplies) plus increased carrying and earning capacity, annual saving (at six round trips per annum), $85,190.94.

4683 (tons of oil per voyage) × 6 = 28,098 tons oil annually

$$\frac{85{,}190.94}{28{,}098.00} = \$3.03 \text{ increased earning capacity per ton of oil used.}$$

$11.61 (cost oil per ton) plus $3.03 (saving) = $14.65 per ton of oil, at which price it would still compete with coal at $8.20 per ton. This equals $2.00 per barrel.

Example II. — Test in large steel plant in Mexico ("Mexican Fuel Oil"):

Coal at $8.50 Mex. per ton (11,500 B.T.U. per pound).
Oil at $2.05 Mex. per ton delivered.
Showed a saving in fuel and expenses of $92,730.00 Mex. annually, with a consumption of 123,302 barrels annually.

$$= \text{saving per barrel of } \frac{92{,}730}{123{,}302} = \$0.75 \text{ Mex. per barrel.}$$

$0.75 plus $2.05 = $2.80 Mex. = $1.35 U. S. gold per barrel, at which price Mexican oil could still compete with coal at $4.13 per ton ($8.50 Mex.).

Example III. — Tests made on United States railways:

These tests show that 125 pounds of fuel oil (approximately 3½ barrels) are equal to a ton of coal.

	Cost per ton-mile.	Price at which oil could compete.
Lehigh coal @ $3.45 per ton (2000 lbs.)	$35.05	$1.30
Lehigh slack @ 3.25 " "	44.61	1.72
Screened lump (Wilburton coal) @ 3.60 " "	32.60	1.21
McAllister Mine:		
Run coal @ 3.50 " "	31.21	1.16
Crude oil @ 4.234 " ($0.58 per bbl.) .	15.62	....

Example IV. — Test on the A. T. & S. F. Ry., between Kansas City and Newton, Kansas:

Tons used.	Cost.	Cost per ton.	Price at which oil still could compete with coal.
349 coal	$663.10	$1.90	$0.80
114 oil (832 bbls.)	457.60	3.85 (0.55 per bbl.)	....

NOTE. — This comparison is based only on the costs per ton-mile of the fuel consumed. The other tests cited above include in the comparison the savings effected in handling and storage.

Example V. — M. J. O'Shaugnessy gives the following data regarding two test runs by ships running between New York and Montevideo, one using coal and one fuel oil under the boilers:

Distance 5761 knots (6825 miles).
Both vessels equal in horse-power and displacement.

	Coal.	Oil.
Time elapsed	29.4 days	27 days
Fuel consumed	813 tons at $3.00	426 tons at $4.00
Cost of fuel	$2439.00	$1704.00 (55¢ per bbl.)
Wages	$249.70	$87.00
Total cost of fuel operations	$2437.48	$2061.77
Cost of power per ton-mile	$0.00014 per ton	$0.00007 per ton
Excess freight-carrying capacity	....	1219 tons
Revenue from this space	....	$7314.00
Total saving of oil over coal	....	$7989.71[1]

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[1] Equals a saving of $2.43 per barrel of oil, or in other words that oil at $0.55 plus $2.43 or $2.98 per barrel would still compete with this coal at $3.00 per ton.

Internal combustion engine. — Tests made by the United States Bureau of Mines (Technical Paper 37) and by the United States Navy show that the relative efficiency of the steam engine to the heavy-oil internal combustion engine (Diesel, etc.) is conservatively 10 : 25; while for marine service the rates of the total power of internal combustion to coal-fired steam engines, considering fuel storage, calorific value of the fuel and engine efficiency, is approximately 10 : 40.25.

One barrel (42 gallons) of California crude weighs 335 pounds and at an average ratio of 10 : 32 would equal

$$335 \times \tfrac{32}{10} = 1072 \text{ pounds of coal, or } 0.536 \text{ ton.}$$

Improvements are still being made in this type of engine adapting it to the use of different types of crude oils. Until recently it could only be used satisfactorily with certain distillates, owing to defective scavenging in the cylinder.

Fuel Economy

Oil storage 11.5, to coal storage 10.

Calorific value of oil 14, to that of coal 10.

Oil burned in an oil engine 25, to oil burned for steam production 10.

From this ratio the cost of either fuel can be calculated from the market quotations. This assumes a good steaming coal of 13,500 B.T.U. per pound, and an average fuel oil of 18,900 B.T.U. per pound. In the case of an inferior coal, say of 10,400 B.T.U. as of a typical western lignite, the ratio must be changed proportionately.

The National Transit Company gives the following comparative figures as to the costs of operating small prime movers with different classes of fuel:

COMPARATIVE COST OF OPERATING SMALL PRIME MOVERS

Kind of fuel	Fuel oil, 3¢ gal.	Natural gas, 30¢ M.	Kerosene, 8¢ gal.	Gasoline, 12¢ gal.	Electric current, 5¢ kw.
Consumption per B.H.P. hr.	0.128 gal.	14.8 cu. ft.	0.106 gal.	0.112 gal.	1.2 kw.[1]
Cost per B.H.P. hour	0.385 ct.	0.445 ct.	0.85 ct.	1.34 cts.	4.5 cts.
Cost of 10 H.P. per hr.	3.85 cts.	4.45 cts.	8.5 cts.	13.4 cts.	45 cts.
Cost per day (10 hr.)	38.5 cts.	44.5 cts.	0.85 ct.	$1.34	$4.50
Ratio of cost	1	1.15	2.2	3.5	11.7
Cost per year (300 days)	$115.50	$133.50	$255.00	$402.00	$1350.00
Actual saving per year	....	$18.00	$139.50	$286.50	$1234.50

[1] 20% motor loss.

The fuel oil figures are based on actual tests of the National Transit 10-horsepower, two-cycle, single-cylinder oil engine.

Gasoline content. — As one of the most valuable fractions of the refining oils is the gasoline, and as many of the fuel oils are now "topped" for their gasoline before being sold as fuel, the following curves are given as showing the variation in gasoline content of the crude petroleums in the principal fields in the United States (Figs. 1–6).

The high content of gasoline in Cushing and Pennsylvania oils should be noted.

The method formerly prevalent of classifying oils into those having an "asphalt" or a "paraffin base," while once useful is no longer justified, since many oils have been discovered with both paraffin and asphalt, and the distinction should therefore be discontinued. Any method, seeking to determine the relative value of two crude oils, should take into consideration the kinds and amount of products obtainable by present refining methods, the distance from the large markets and refineries, the pipe line and railroad facilities, and the relation of the production and consumption curves in this country.

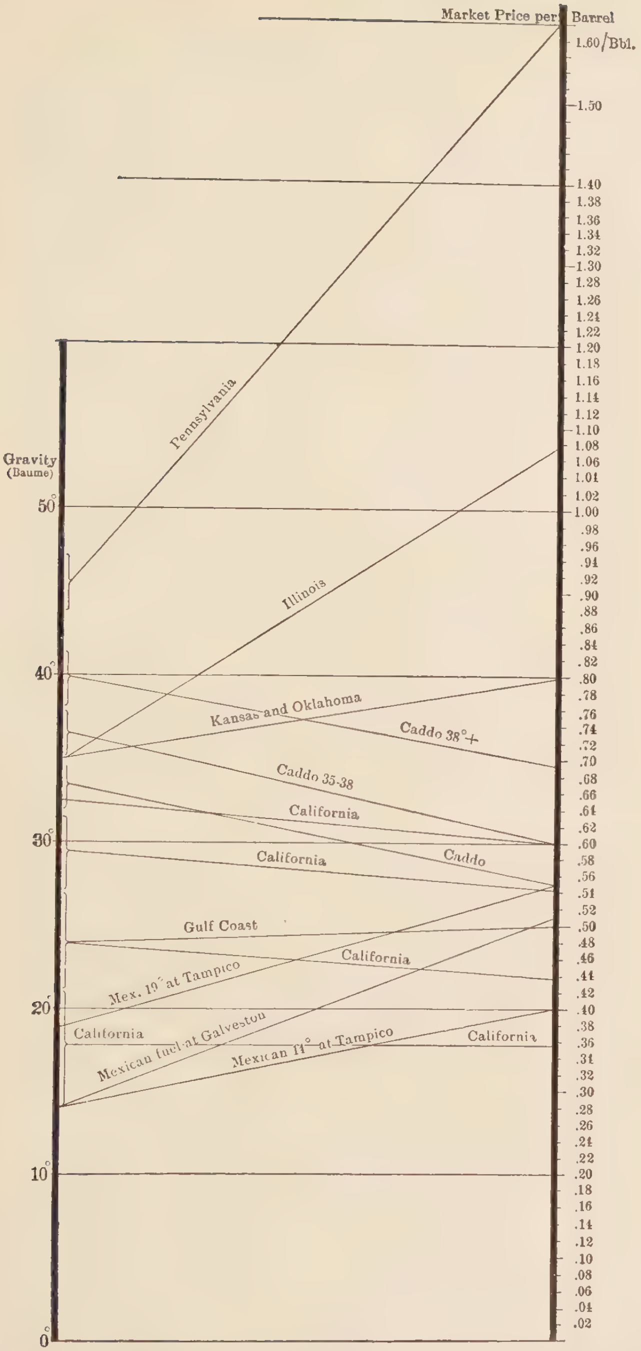

FIG. 13. Diagram showing the relative market prices of crude oil from different fields during the recent period of low prices, with their respective gravities.

Natural gas. — Natural gas as here used is the term applied only to those gases occurring in rocks, of a sufficiently inflammable nature to be used as a fuel or illuminant. Volcanic gases might be included, but they are outside the scope of this discussion.

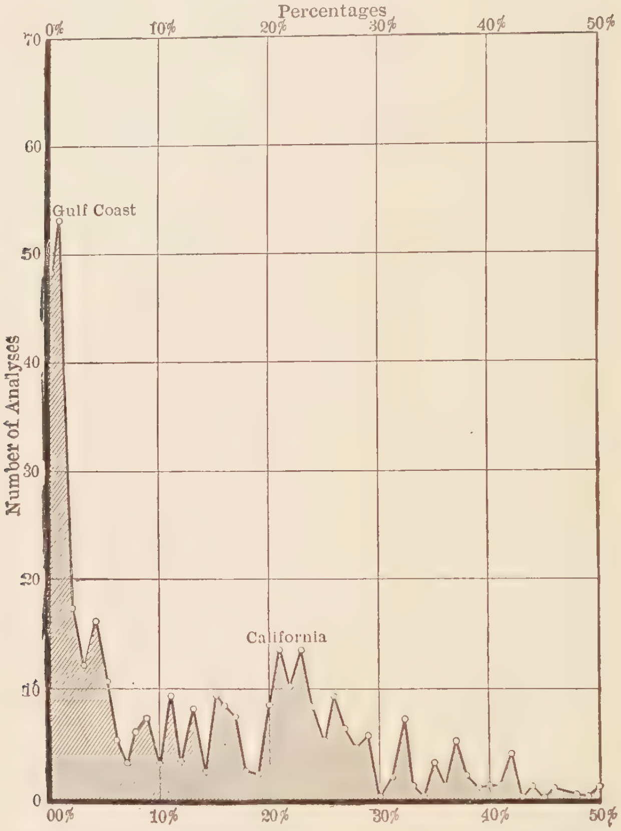

FIG. 14. Percentages of asphaltum residue in the crude oils of the United States.

Natural gas may be divided broadly into two general types: (1) "dry" gas, whose combustible hydrocarbon constituents consist principally of methane (CH_4) with some nitrogen and ethane (C_2H_6), and (2) "wet" or casing-head gas, which contains besides methane varying amounts of the heavier hydrocarbons, from ethane (C_2H_6) to hexane (C_7H_{16}).

Casing-head or "wet" gas is yielded with the oil in many oil wells, and also by gas wells located in oil pools and producing from the same stratum as the oil. This is the type of gas used in making gas-gasoline. Analyses of such gases will frequently have all hydrocarbons heavier than methane reported as "ethane" (the next heavier hydrocarbon in the paraffin series), or simply as 'heavier hydrocarbons."

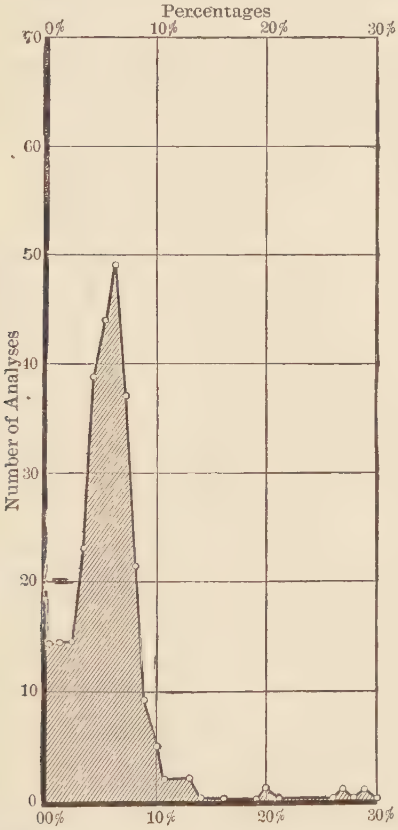

Fig. 15. Percentages of paraffin wax in the crude oils of the United States.

While natural gas from different localities will vary considerably in calorific value, no discrimination is usually made in price for these differences. Some of the fields in southern Kansas produce gas very high in nitrogen, which of course dilutes the hydrocarbon content and lowers the calorific value of the gas. Where there is a richer gas available for the pipe lines sometimes they will not take this poor grade;

but as the supply declines, and an increasing proportion is used for domestic purposes, much of this poorer gas will be mixed in the pipe line with that from the other pools.

Natural gas is still so plentiful that it is sold much cheaper than artificial gas of one-half its heating value. In the United States in the year 1912 the following average prices prevailed for natural and artificial gases:

	Cents per M.
Natural gas for all purposes, average price	15.04
Oil and water gas as an illuminant	92.40
Oil and water gas as a fuel	99.00
Coal gas for all purposes	41.00

The general average price for manufactured gas for all purposes was 70 cents, as against 15 cents for natural gas, while the latter has a much higher heating value, as shown by the following table:

	B.T.U.	Calorific intensity.
Natural gas (Pittsburg)	948	1852° C.
Oil gas	828	1915
Coal gas from retorts	625	1896
Coke-oven gas	569	1892
Carburetted water gas	563	1914
Water gas	292	1928
Producer gas (with steam)	146	1696
Producer gas (ordinary)	148	1555

Natural gas may be regarded as the ideal fuel, because of its cleanliness, low degree of toxicity, ease of handling and efficiency of combustion. Its only drawback is the necessity of extensive pipe lines, and compressor stations where transported to a distance.

Where natural gas enters into competition with coal, the latter largely determines the price of the former for certain commercial purposes. In any district the two may be compared by substituting values in the following equations:

$$\left(\frac{\text{B.T.U. per pound of coal} \times 2000}{\text{B.T.U. per cubic foot of gas}}\right) = \left\{\begin{array}{l}\text{Cubic feet of gas equal to 1 ton}\\ \quad\text{of coal.}\end{array}\right.$$

$$\frac{\text{Cubic feet of gas equal to a ton of coal}}{1000} \times \text{Price of gas per 1000 cu. ft.}$$
$$= \text{Price per ton of coal which will compete.}$$

Example. — Assuming coal to have 14,000 B.T.U. per pound, gas to have 1000 B.T.U. per cubic foot, at 15 cents per 1000 cubic feet,

$$\frac{14{,}000 \times 2000}{1000} \div (1000 \times 0.15) = \$4.70 \text{ per ton.}$$

The cost of handling the two fuels and the relative costs of installations must be taken into consideration. When the price of gas goes up beyond a point where it competes with coal, it is then dropped out of a majority of the commercial plants such as smelters, steel plants, canneries, brick plants and potteries, unless the coal of the district is so high in undesirable constituents, such as sulphur, as to make it necessary to treat it before using. Gas is then restricted to domestic and special uses, where its cleanliness and convenience make it still preferable. Natural gas then comes into competition with artificial gas, and the price may be raised to a point nearly double the cost of manufacturing gas, owing to the higher calorific value and lower toxicity of natural gas. This higher price of natural gas will in the future tend to restrain waste and lead to the development of many low-pressure gas fields and also to deeper drilling in old fields.

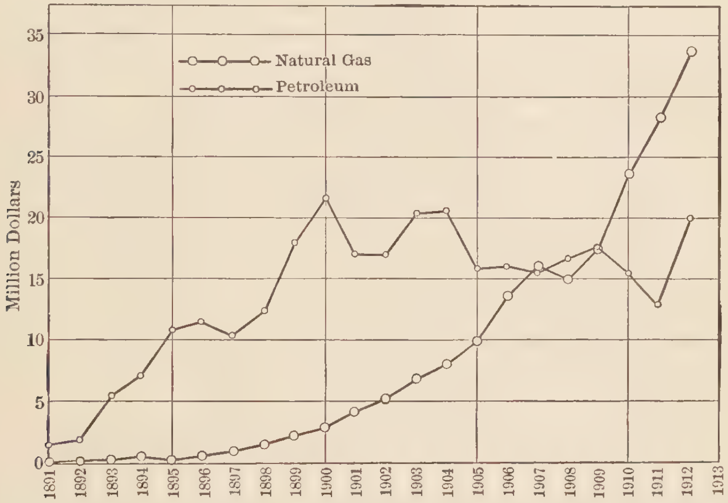

FIG. 16. Showing the value of natural gas, from 1882 to 1912, compared with the value of petroleum, from 1859 to 1912, in the United States, in millions of dollars.

Natural gas has been used for compression to compete with Pintsch gas, for lighting railroad trains. It has also been compressed and used for driving automobiles. With the increasing price, such methods will be still further adapted in the future to facilitate transportation of the gas for special purposes without the necessity of pipe lines.

The only countries which have in the past used natural gas for commercial and domestic purposes to any extent have been the United

States and Canada. This is partly due to ignorance, partly because other fields are at a considerable distance from the market, and partly because the most important of these foreign fields produce gas from Tertiary formations where individual wells are shorter lived than in Paleozoic rocks. Fig. 16 shows the increasing value of the natural gas produced in the United States and Canada, compared with their production of petroleum, from the beginning of their exploitation until 1912. With increased prospecting in the older formations, natural gas fields will be developed to a greater extent in other continents.

Casing-head gas is frequently used for fuel in drilling operations in the field in which it is produced, and some towns such as Warren, Pa., and St. Mary's, W. Va., have been supplied with such gas. However, the new methods of extracting gasoline from such gases are resulting in their being utilized for this purpose where available in considerable amounts. The residual gas, after the extraction of the heavier hydrocarbons, of course still contains its methane and ethane content and may then be sold or used as "dry" natural gas.

The following table shows the analyses of the pipe line runs of natural gas supplied in the cities named:

Pipe line supply.	Methane.	Other hydrocarbons.	Nitrogen.	Other constituents.
	Per cent	Per cent	Per cent	Per cent
City of Pittsburg, Pa. — Gas from W. Va. and Pa.	82.00	16.4	1.5	....
North Western N. G. Co. — Oil City, Pa.	95.42	....	4.51	0.07
Prairie Oil & Gas Co. — Parsons, Kan.	91.90	3.37	3.74	0.99
Kansas N. G. Co — Lawrence, Kan.	98.00	....	1.88	0.12
Town Supply of Eureka, Kan.	51.40	....	46.40	2.20

The calorific value of any gas may be calculated from its analysis, by the use of the figures given in the following table, taken from Richard's "Metallurgical Calculations."

Constituents of natural gas.	B.T.U. per cubic foot.	Constituents of natural gas.	B.T.U. per cubic foot.
Methane CH_4	966	Ethylene C_2H_4	1627
Ethane C_2H_6	1728	Propylene C_3H_6	2385
Propane C_3H_8	2477	Acetylene C_2H_2	1846
Butane C_4H_{10}	3447	Carbon monoxide CO	344
Pentane C_5H_{12}	4250	Hydrogen H_2	293.5
Hexane C_7H_{16}	5012	Hydrogen sulphide H_2S	619

Example. — Given a gas from Indiana with the following analysis: One cubic foot contains:

	Per cent.
Methane CH_4	94.16
Hydrogen H_2	1.42
Ethane C_2H_6	0.30
Carbon dioxide CO_2	0.27
Carbon monoxide CO	0.55
Oxygen O_2	0.32
Nitrogen N_2	2.80
Hydrogen sulphide H_2S	0.18

		B.T.U.
CH_4	0.9416 × 966	909.5856
H_2	0.0142 × 293.5	4.1677
C_2H_6	0.003 × 1627	4.881
CO	0.0055 × 344	1.892
H_2S	0.0018 × 619	1.1142
	Total B.T.U. per cubic foot	921.64

References for natural gas are:

U. S. Geological Survey, Mineral Resources for all years.

J. C. McDowell, "The Future of the Natural Gas Industry in America," paper read at the Tenth Annual Meeting of the Natural Gas Association of America, Cincinnati, May, 1915.

J. A. L. Henderson and W. H. Henderson, "Inflammable Natural Gas as an Economic Mineral," Proceedings of the Institution of Mines and Metallurgy, Jan. 21, 1915.

Westcott, H.P., "Handbook of Natural Gas."

CHAPTER II

THE ORIGIN OF OIL AND GAS

This question has been discussed so many times, from the standpoint of so many apparently conflicting groups of facts which are known regarding the composition and occurrence of petroleum, that no attempt will be made in this treatise to go into them exhaustively. For a recent discussion of this question the reader is referred to Clarke's "Data of Geochemistry" (U. S. G. S. Bull. 616). These different theories fall into the following groups:

- *A*. Cosmic.
- *B*. Inorganic.
- *C*. Organic.
  - *a*. Material.
    1. Plant, especially diatoms and salt marsh plants.
    2. Animal.
  - *b*. Method.
    1. Bacterial formation.
    2. Heat.
    3. Compression with heat.

Cosmic. — This hypothesis is based on the observed occurrence of small amounts of hydrocarbons in meteorites, and supports the idea that these substances were a part of the original earth material at the time of its formation. It is acceptable for unimportant, disseminated hydrocarbons, but not for the great commercial deposits.

Inorganic. — This type of hypothesis is one which has been held in the past by chemists, and is supported by synthetic experiments in the laboratory. However, the geological evidence which is still piling up as new fields develop, is opposed to this, in most localities. One of the commonest assumptions made in support of this is that large amounts of metallic carbides at great depths react with descending waters and form various gaseous hydrocarbons, which by heat and pressure and filtration are subsequently changed into petroleum and natural gas. The existence of such a circulation, however, is questionable.

Organic (1) plant. — The popular theory that oil has been formed in some such way and from similar materials as coal is widely held, although without sufficient evidence. Certain authors believe that while the original material may have been largely the same, conditions of deposition of the bed in question and subsequent strata have determined whether the resultant material would be coal or petroleum. The possible influence of salt and of certain species of bacteria will be dealt with at greater length in a succeeding paragraph.

Analyses by the United States Bureau of Mines[1] show that there is a complex series of organic compounds, some of them hydrocarbons, in the volatile portion of certain bituminous and lignitic coals, and that probably certain of these are similar to those found in petroleum. However, no true transition stage between coal and petroleum has been reported, although the junior author has observed a rather significant juxtaposition of the two in certain Cretaceous strata in northern Alberta. It is a fact that many coal beds occlude considerable quantities of methane gas, and in at least one locality in West Virginia gas wells produce from the Pittsburg coal bed.

However, all forms of vegetable detritus by their nature are not capable of being transformed into coal because not sufficiently free from admixture with inorganic material. There is undoubtedly a greater amount of petroleum- and gas-forming organic detritus than there is of that which might be transformed into coal. Hence oil may be and is encountered in many formations where there are no coal beds, such as the Devonian of Pennsylvania, West Virginia and Ohio. Also it may be said that any oil formed contemporaneously with coal would, during the period of compacting, by the action of selective segregation, find its way for the most part into more porous beds.

Arnold and Anderson[2] have found very strong evidence in the formations of the California fields which points to oil having been formed from the remains of diatoms and foraminifers. Several of the formations in those fields are diatomaceous, while the Monterey shale (2500 feet thick) is made up almost very largely of diatoms. While as in other fields the oil is now found in porous sand beds, nevertheless these sand beds are found to contain oil only at such places where they have a direct connection with the shales containing diatoms, either (*a*) through faulting, (*b*) conformable deposition or (*c*) unconformable deposition. At places where the Monterey shale ceases to contain diatoms, the adjacent sand bodies are barren of oil, while other sands in juxtaposition to lower diatomaceous shales are productive. These conditions have been proved to exist throughout many of the California fields, and have been reliable guides in prospecting. This success is the best of evidence for the diatomaceous origin of the oil in these districts.

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[1] Frazer and Hoffmann, U. S. Bur. Mines Tech. Paper 5.

[2] Arnold and Anderson, U. S. G. S. Bull. 322, 109. Anderson and Pack, U. S. G. S. Bull. 603, 198.

It is to be hoped that there will be more coöperation between chemists and geologists in correlating new evidence in other fields with a view to determining the origin of the oil.

Organic (2) animal. — Oil is found in limestone formations in only a few notable instances, where it has been rendered porous through dolomitization, strong jointing, intrusions or water channels. Such are the Lima-Indiana fields producing from the dolomitic Trenton limestone, the Petrolia-Oil Springs pool in Ontario producing from the porous limestones in the Dundee formation, and the Mexican fields producing from the fractured and channelled Tamasopa and San Felipe limestones. In each of these fields, the oil-bearing limestone is overlaid by dark petroliferous shales or marls.

Limestones are usually compact and massive, and unless later conditions render them porous, as has been the case in the fields named above, they cannot act as reservoirs for oil or gas. As is well known, limestones are composed of the calcareous skeletons of marine animals or organisms, in many cases of microscopic size. It has been pointed out by Craig[1] and others that the absence of phosphates in the composition of petroleum, as well as their absence in the vicinity of any large deposits of oil, is evidence against the origin of any considerable quantities of oil from a limestone source. Even more weighty is the history of the deposition of limestone deposits. As can be observed, the present generation of such lime-secreting organisms lives upon the fatty remains of the preceding generation, either directly or indirectly. Since a large part of the dead animals is consumed by the living, there is little chance for the entombing and accumulation of fats. No traces of fats can be found in a coral bank, except on the surface of the coral. The consumption of the remains of plant life, especially that of the vascular plants, the decomposition of which is delayed sufficiently to permit the burial of a great deal of it before complete decomposition, does not proceed in the same manner, as is evidenced by the great quantities of finely divided carbonaceous matter throughout so many shale beds and other formations. Also to judge from conditions as they exist today, we find the evidence is strongly in favor of the assumption that the greater part of the oil has been formed from vegetable remains. However, Engler and others have demonstrated in the laboratory the production of hydrocarbons from the fats of marine animals, and it must be admitted that such evidence is at least equally as strong in favor of the animal as of the vegetable theory.

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[1] Craig, E. H. Cunningham, Oil Finding.

It has been known since 1835 that the polarized ray was rotated by petroleum; and later Rakusin and Lewkowitsch pointed out that this rotation could be produced by the alcohols, cholesterol and phytosterol, elements found in animal and vegetable fats respectively. Oil derived from inorganic materials is entirely inactive. On the basis of such tests Dalton states:

> "There seems to be no reasonable room for doubt that the optical activity of petroleum is due to cholesterol and phytosterol. . . . Not only do they establish beyond question the organic origin of petroleum, but also since the alcohols in question occur in the fatty parts of animals and vegetables, it confirms Engler's hypothesis that these parts play the principal rôle in the formation of mineral oils. . . . One is led, therefore, to regard the great majority of oils as derived from the decomposition, during long ages, at comparatively low temperatures, of the fatty matters of plants and animals, the nitrogenous portions of both being eliminated by bacterial action soon after the death of the organism. The fats and oils from terrestrial fauna and flora may have taken part in petroleum formation, but the principal rôle must, from the nature of most petroliferous deposits, have been played by marine life."

Bacterial formation. — C. B. Morrey[1] has referred to the rôle of bacteria in organic decay and hence possibly in the origin of oil. He fails, however, to distinguish between the following types of bacterial decay, a distinction which is all-important in this connection:

(*a*) *Sub-aerial decay.* — The bacterial flora here accomplishes so complete an oxidation that there is a minimum of coal or oil formed. The carbon is largely dissipated as carbon dioxide.

(*b*) *Fresh-water decay.* — The bacterial flora here also oxidizes so actively that only limy deposits remain, giving us marl.

(*c*) *Bog-water decay.* — The action by the bacterial flora in this case is such that while there is some formation of methane (marsh gas), the plant remains are in large part not oxidized, but preserved as peat, lignite or coal.

(*d*) *Salt-water decay.* — The bacterial flora in this case, while more actively oxidizing animal materials, affects plant remains in such a way that methane is formed but apparently less coal or other carbonaceous deposit is produced.

One hesitates to offer any additional unsupported ideas in this theory-rich and data-poor field, but may not another product in this last case be petroleum? This does not seem highly improbable in the light of the well-known formation of methane by bacteria. It is also supported by the frequent association of salt-water lagoon muds with bodies of sand such as make up our oil sands. Work by the bacteriologist and biochemist in salt-water decay is greatly to be desired.

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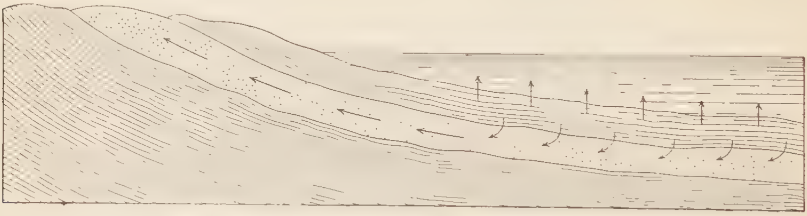
[1] Geol. Survey of Ohio (4), Bull. 1, p. 313.

Dynamo-chemical origin. — Just as it is known that some gas is formed bio-chemically, and it is surmised that some oil may so originate, so we know that some gas is formed dynamo-chemically and we surmise that some oil may be similarly formed.

The direct evidence in the case of gas is the loss of hydrogen from coals subjected to pressure or heat, and the very common inclusion of CH_4 in coal and its escape therefrom.

A great deal more gas than oil must have been formed from the buried organic material. There has been a great deal of both biochemical gas and dynamo-chemical gas, but an overwhelming percentage of the bio-chemical gas was lost at or soon after the time of formation. This loss is very evident in the lagoons back of our beaches. Since the hydrocarbon gases are in general slightly soluble in water, some of it is lost by being carried away in solution, since there is a current of water available for a long time. There is on the contrary a relatively slight loss of dynamo-chemical gas. Yet in spite of this, much of it is of course unavailable because lying at too great depth or in rocks of too low or too fine porosity.



After King, U. S. G. S. 19th Ann. Rpt., Pt. 2, p. 80.

FIG. 17. Diagrammatic section showing the flow of connate water and gas, due to compacting of sediments.

The situation in regard to gas is relatively plain, as compared with oil. The main reason for believing that in the case of oil the biochemical origin is important is that oil moves through compacted water-wet shales (Fig. 17) with such difficulty that much of the oil must have arisen very early before the compacting had been carried very far. On the other hand, David White[1] has shown that the oils associated with low-volatile coals are much lighter. This must be the result of new dynamo-chemical oil contributed to these reservoirs or else the result of transformation of the old oil. In either case it increases the probability of transformation by similar causes from other organic compounds.

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[1] Jour. Wash. Academy of Sci., V, 189–221.

The word "dynamo-chemical" has been used above to include the action of the heat generated by the pressure as well as the pressure itself. The relative rôle of the pressure and this pressure produced heat cannot yet be apportioned. Experimental work along the lines of Bergius,[1] who has produced gas by strongly compressing coal already at 340° C., is greatly needed.

The term distillation has been used a great deal in describing the phenomenon discussed above, but it is well to replace it by White's terms, since condensation following volatilization is not always a feature.

Richardson[2] has recently suggested that "surface phenomena" might contribute to the theory of the origin of oil.

The Relation of the Quality of Oil to Deformation

David White has given us two of the most valuable recent discoveries in connection with petroleum and natural gas in the two following laws:

> (1) "In regions where the progressive devolatilization of the organic deposits in any formation has passed a certain point, marked in most provinces by 65 to 70 per cent of fixed carbon (pure coal basis) in the associated or overlying coals, commercial oil pools are not present in that formation nor in any other formation normally underlying it, though commercial gas pools may occur.
>
> (2) "The lowest rank oils of each type are found in the regions and formations in which the carbonaceous deposits are least altered, . . . the highest rank oils being, on the whole, found in regions where the carbonaceous deposits . . . have been brought to correspondingly higher ranks."

It is proposed to consider here the cause of this relationship. Let us first assemble in a convenient form these and other principles that might have a bearing upon the problem. There is an inverse correlation in some degree between:

(*a*) Greater age of the formation and specific gravity of the oil (Engler).
(*b*) Greater age of the formation and ratio of volatile to fixed carbon compounds in the organic detritus (Hilt).
(*c*) Greater age of the formation and ratio of oil to gas in the reservoirs.
(*d*) Depth of reservoir from surface and specific gravity of the oil.
(*e*) Depth of reservoir from surface and ratio of volatile to fixed carbon compounds in the organic detritus.
(*f*) Depth of reservoir from surface and ratio of oil to gas in the reservoir.
(*g*) Depth of reservoir from surface and percentage of water in the reservoir.

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[1] Bergius, F., Jour. Soc. Chem. Ind., Vol. 32, p. 462.

[2] Richardson, C., Journal of Ind. and Eng. Chemistry, Vol. 8, p. 4.

(*h*) Amount of deformation without faulting and specific gravity of oil.

(*i*) Amount of deformation without faulting and ratio of volatile to fixed carbon compounds in the organic detritus.

(*j*) Amount of deformation without faulting and ratio of oil to gas in the reservoir.

(*k*) Amount of deformation without faulting and percentage of water in reservoir.

We may construct from these the following principle:

A typical reservoir containing oil and gas has the following history: A gradual increase in its gas content by virtue of which there is a gradual loss of its oil and water content, the water being lost more rapidly. The oil by addition of lighter new components becomes gradually lighter, while still retaining some of the original constituents.

The hypothesis here proposed in explanation of this history is that the increased dynamo-chemical activity with increased depth and increased folding produces a continual evolution of gas and oil from the organic detritus, and to a much less degree from the previously formed oil; that the successive quantities become increasingly gaseous, and those that are liquid lighter and lighter, as the dynamo-chemical agency becomes more intense. This is suggested by the recent work in "cracking" oil under pressure.

In accordance with the principle of selective segregation, discussed by the senior author in the February bulletin of the American Institute of Mining Engineers (1915), the newly formed gas accumulates in the porous reservoirs and displaces the fluids there, pushing them back into the surrounding rock. This gas bears vapors which condense upon the relief or cessation of the thrust, or upon the diminution of the depth by denudation. This condensate, together with some oil newly formed directly as a liquid, added to the oil already in the reservoir, makes the oil lighter. The high carbon residues that might otherwise be looked for in the sand are left in the shales.

One reason for believing that the reaction is more active with the organic detritus than with the previously existing oil is that the dynamo-chemical agencies are far less effective on fluids in a porous reservoir, due to the fact that the pressure is almost immediately distributed to all the reservoir content, and so is less intense at any one point. On the other hand, the detritus being solid, the adjustment is interfered with, so that greater stress is effective at certain points. Imagine a rod of porous sandstone to be bent. The pressure of the reservoir contents would be scarcely affected as a whole, yet some of the cement and grains would be subjected to great stress.

In conclusion, selective segregation and the expulsion of the fluid contents of reservoirs by new dynamo-chemical gas furnish us an interpretation of White's laws of correlation between the rank of coal and the presence or absence of oil. The lighter quality of the later dynamo-chemical oil gives us the clue to the correlation of the rank of coal with the rank of oil.

Another way in which deformation may cause the oils to be lighter is from capillary fractionation. Dr. David T. Day[1] long ago pointed out that the oil in passing through dry fuller's earth loses disproportionate amounts of its unsaturated compounds, its sulphur compounds, and its heavier components.

Now since deformation increases the amount of dynamo-chemical gas formed, migration is greater which results in making the oils higher in rank.

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[1] Day, David T., Proc. Am. Philos. Soc., 36, No. 154, 1897. Trans. Petroleum Congress (Paris), 1900. Day, D. T., Gilpin, J. E. & Cram, M. P., U. S. G. S. Bull. 365. Gilpin, J. E., & Bransky, O. E., U. S. G. S. Bull. 475.

CHAPTER III

THE DISTRIBUTION OF THE OIL AND GAS

The stratigraphic distribution of oil. — Oil was first produced in the United States from the Devonian sandstones of Western Pennsylvania, in 1859. Within the next few years, oil pools were developed in the formations of Devonian age both in Pennsylvania and the Ontario peninsula in Canada. From this beginning, development work brought production in the Devonian and Carboniferous formations in New York, Pennsylvania, West Virginia, Ohio, Kentucky and Tennessee, comprising the present Appalachian fields. During this development, this country and Canada contained the only fields in the world producing from these older formations, and this remains practically true today.[1]

Roumania has been producing since before 1857, and Russia since 1863, from formations of Tertiary age. Besides these two countries, petroleum is being produced from Tertiary formations in Italy, Galicia, Germany, Japan, India, the Dutch East Indies, Peru, Trinidad, and the California and Gulf Coast fields in the United States. But nowhere except on the North American continent is oil in any quantity produced from Paleozoic rocks.

From the chart (Fig. 18), it will be seen that in point of quantity these Tertiary oils comprise 57 per cent of the world's total production, while the next important group of oil-producing sands is in the Paleozoic of the United States. The Lower Cretaceous, Jurassic, Triassic and Middle and Upper Permian rocks as found in North America are nearly barren of oil or gas so far as prospected. These formations are relatively poor in organic remains, as they are found on the present continent. However, a large proportion of these sections may represent fresh water and arid deposits of the continental interior, while the formations of these ages, laid down on what was then the continental shelf and which probably contain oil and gas, have probably remained in large part submerged and so overlaid as to be beyond reach of prospecting.

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[1] U. S. Geological Survey, Mineral Resources of the United States, 1896 to date, and Westcott, "Handbook of Natural Gas."

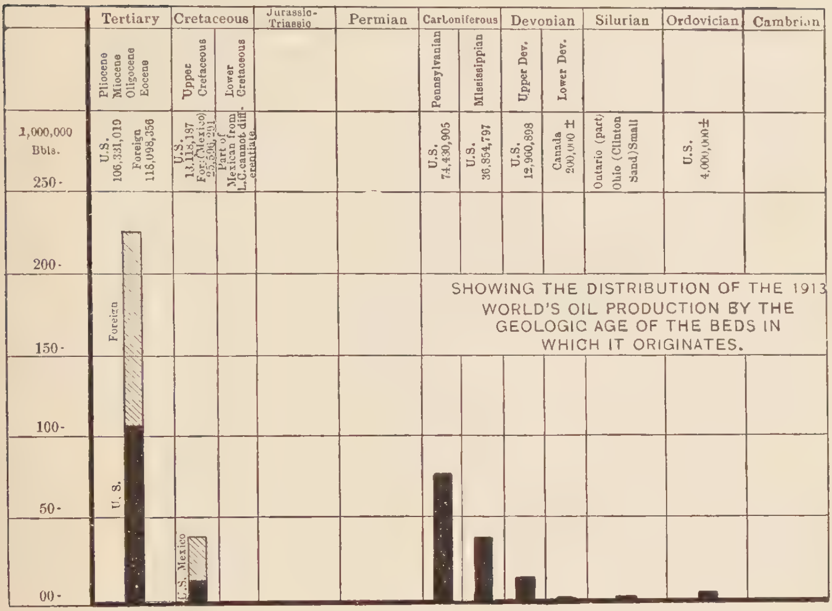

Tertiary
Cretaceous
Jurassic-Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Pliocene Miocene Oligocene Eocene
Upper Cretaceous
Lower Cretaceous
Pennsylvanian
Mississippian
Upper Dev.
Lower Dev.
1,000,000 Bbls.
U.S. 106,331,019
Foreign 118,098,356
U.S. 13,118,197 For: (Mexico) 25,596,291
Part of Mexican from L.C. cannot differentiate
U.S. 74,430,905
U.S. 36,854,797
U.S. 12,960,898
Canada 200,000 ±
Ontario (part) Ohio (Clinton Sand) Small
U.S. 4,000,000±
250
200
150
100
50
00
Foreign
U. S.
U.S. Mexico
SHOWING THE DISTRIBUTION OF THE 1913 WORLD'S OIL PRODUCTION BY THE GEOLOGIC AGE OF THE BEDS IN WHICH IT ORIGINATES.

FIG. 18.

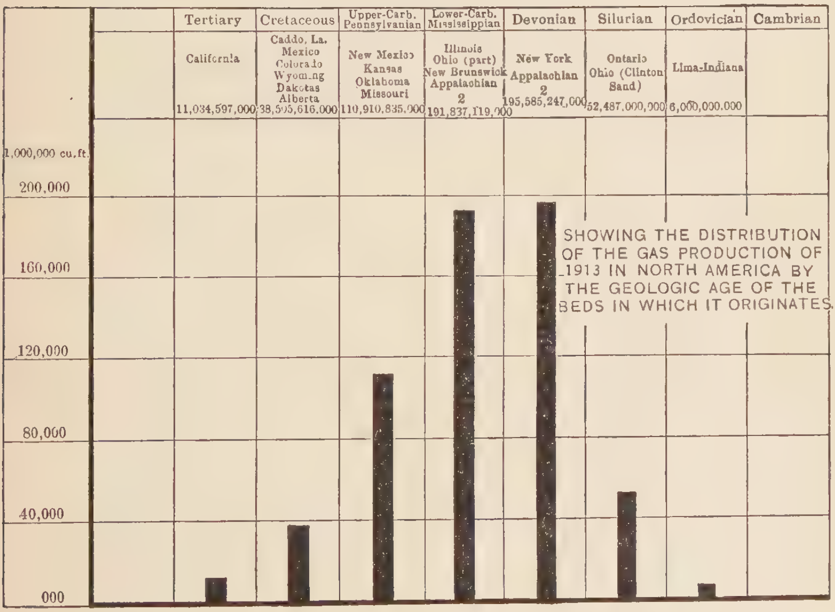

Tertiary
Cretaceous
Upper-Carb. Pennsylvanian
Lower-Carb. Mississippian
Devonian
Silurian
Ordovician
Cambrian
California
11,034,597,000
Caddo, La. Mexico Colorado Wyoming Dakotas Alberta
38,595,616.000
New Mexico Kansas Oklahoma Missouri
110,910,835,000
Illinois Ohio (part) New Brunswick Appalachian
2
191,837,119,000
New York Appalachian
2
195,585,247,000
Ontario Ohio (Clinton Sand)
52,487,000,000
Lima-Indiana
6,000,000.000
1,000,000 cu.ft.
200,000
160,000
120,000
80,000
40,000
000
SHOWING THE DISTRIBUTION OF THE GAS PRODUCTION OF 1913 IN NORTH AMERICA BY THE GEOLOGIC AGE OF THE BEDS IN WHICH IT ORIGINATES.

FIG. 19.

The fact that the prolific fields of Europe and Asia were originally developed in the younger Tertiary formations, has probably had an effect in limiting prospecting to such strata outside of North America, and has led to over-emphasis upon the importance of surface indications, which are more common in the younger and softer rocks. This emphasis is apparent in most of the literature upon these fields. Owing to the much greater age and hardness of the Paleozoic rocks, surface indications of oil and gas are much less frequent, so that the lack of seepages is less significant than in younger formations. It is probable that considerable production will some day be developed in the older formations, when they have been thoroughly prospected in Europe and Asia.

There is no oil produced from rocks of Cambrian age, although a few small surface indications are known. There are two reasons which may account for this:

(*a*) Due to displacement by new dynamo-chemical gas, the oil has probably been largely forced out of these old reservoirs; which are, therefore, more favorable for gas than oil (Johnson, "The Rôle and Fate of Connate Water," Bull. A. I. M. E., Jan., 1915).

(*b*) By far the larger part of the Cambrian formations lie so deep as to be beyond the reach of the drill, and hence have been little prospected.

The stratigraphic distribution of gas. — There is a correlation between the age of the rocks, and the ratio of gas to oil in the reservoirs.

The following table gives the order of prominence of these formations as producers of oil and gas respectively, as shown graphically in the charts (Figs. 18 and 19):

ORDER OF PROMINENCE

Oil	*Gas*
1. Tertiary	1. Devonian
2. Carboniferous	2. Carboniferous
3. Cretaceous	3. Cretaceous
4. Devonian	4. Silurian
5. Ordovician	5. Ordovician
6. Silurian	6. Tertiary

While in general the older the rocks, the greater the proportion of gas to oil, yet as the older rocks are less exposed at the surface and less accessible to the drill, they may be thus thrown out of their natural order so far as actual production is concerned. Thus it might be expected that Ordovician rocks would outrank the Cretaceous as a producer of gas; but as so relatively little of the Ordovician is accessible for prospecting, there is but one field (Lima-Indiana) in which gas is actually produced in any important quantity. Gas with some light oil is found in a well drilled into what seems to be the Burgen sand (St. Peters) in the Osage Nation, Oklahoma, and it is possible that a larger supply will be developed in this bed when prices warrant the difficult drilling through the overlying chert.

Notwithstanding the fact that natural gas has been known and utilized from time to time by the priests of religious cults in both Europe and Asia, and by Chinese as a fuel in their salt works two thousand years ago, yet its value has never been largely realized in modern industry except in the United States and Canada. This may be explained partly by the fact that during the short period of modern drilling methods, all development in Europe and Asia has been in the soft, unconsolidated Tertiary formations. Gas is encountered in most of the oil fields in those countries, and in Transylvania in Hungary a number of very large gas wells have been encountered. However, such wells have invariably been short-lived, and the supply so limited in most cases that it would apparently not pay to invest large capital in building pipe lines, compressor stations and distributing plants to the centers of population. But the importance of natural gas as an economic factor is becoming recognized, and with increased prospecting in older formations in both Europe and Asia, there will no doubt be developed large and long-lived supplies of this valuable fuel.

Historical significance. — In a country like the United States, where geological conditions are known, weight should be given to past experience in drilling in certain formations. Strata of some ages are known to be more valuable producers of oil and gas than others, and chances of developing production where other conditions are favorable are correspondingly increased. However, this is not a safe guide when prospecting or developing territory on a relatively unknown continent. The Jurassic and Triassic rocks may contain no hydrocarbons in the United States, and yet in another part of the world where conditions of deposition and organic life were different during these ages, the chances for developing oil or gas production may be quite good. The oil found in the Jurassic formations of Argentine is a case in point. When studying a new country, it is better to judge oil and gas possibilities by the character of the sections encountered, rather than to be prejudiced by the fact that rocks of that age have not been found to be oil-bearing on another continent.

However, certain general laws may be stated, which will hold true for all districts:

(*a*) The older the formation, the greater the ratio of gas to oil in its reservoirs.

(*b*) The younger the rocks, the greater the percentage of water in the total contents of the reservoirs.

(*c*) The older the formations, the less reliance can be placed upon the lack of surface "shows."

Fig. 91 shows the areas in North America representing the surface distribution of the metamorphic and plutonic rocks of the Archeozoic and Proterozoic formations. These areas may be considered as hopeless for developing oil or gas production, because there is either a lack of organic matter or a lack of porosity such as is necessary for a reservoir.

CHAPTER IV

THE RESERVOIRS OF OIL AND GAS

The nature of the reservoir. — The reservoirs yielding oil and gas may exist in strata of various sorts, of which the following are the principal types:

1. Sandstone (sometimes unconsolidated sands).
2. Dolomitic and jointed limestone.
3. Water-channeled limestones.
4. Fissured rock.
5. Other porous rocks.

1. The Appalachian, Illinois and Mid-Continent fields, and the Silurian sands (Clinton and Medina) in Ontario, are with few exceptions of the consolidated sandstone type. The Tertiary fields of California, Russia, Galicia, Roumania and Peru produce oil largely from soft unconsolidated sands, while the Cretaceous fields of the Sabine uplift in Louisiana and Texas, Wyoming and Alberta are much softer and less consolidated than those producing from the rocks of the Paleozoic and older formations.

2. The oil in the Lima-Indiana field is produced from the dolomitic Trenton limestone. Farther north on Manitoulin Island these beds contain many joint cracks filled with " tar."

3. The Mexican fields furnish a famous example of extensive water-channelling accompanying fractures in the Tamasopa limestone and overlying shales.

4. Several small pools in the Appalachian fields produce some oil from fissured and jointed shale, among which may be mentioned the Gaines and a pool near Warren in Pennsylvania. The Boulder and Florence pools in Colorado produce from fissured Cretaceous shales, and some of the wells in the Mexican fields produce from fissured shale beds in the San Felipe series (Upper Cretaceous).

5. The saline dome pools of the Gulf Coast field are examples of oil accumulations accompanying secondary water-deposited beds of salt and gypsum and sulphur. Among other porous rocks may be

mentioned the small amount of petroleum found in granites and basalts in Quebec, Mexico, Oregon and elsewhere. No production has ever been derived from such localities, the oil, where found, being in small amounts and having been in most cases obviously derived from nearby sedimentary rocks.

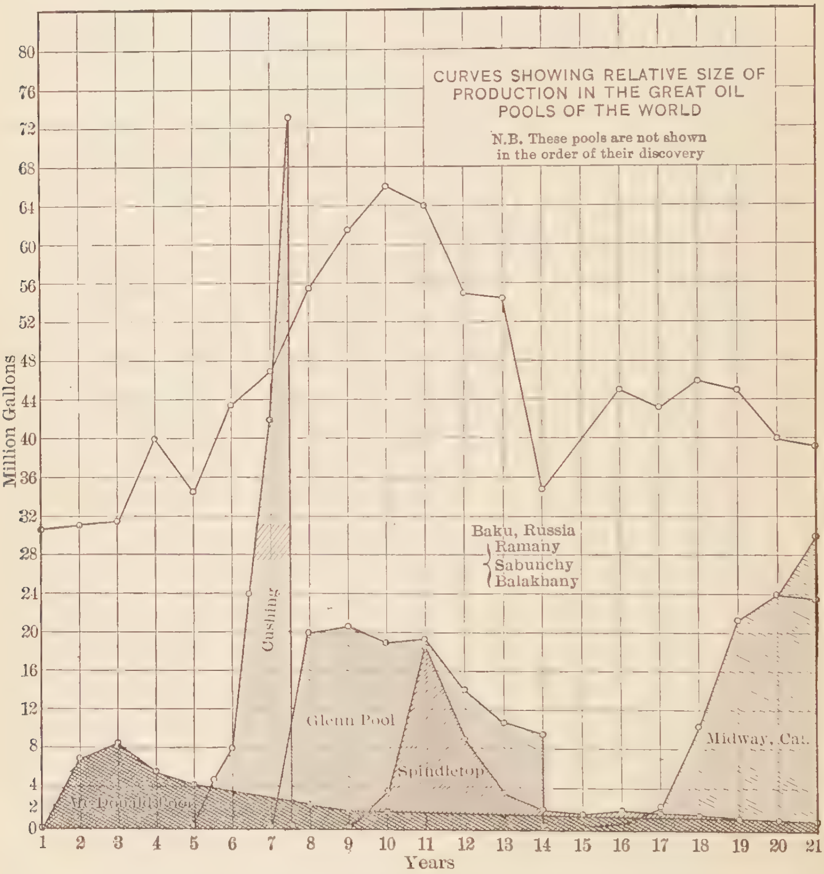
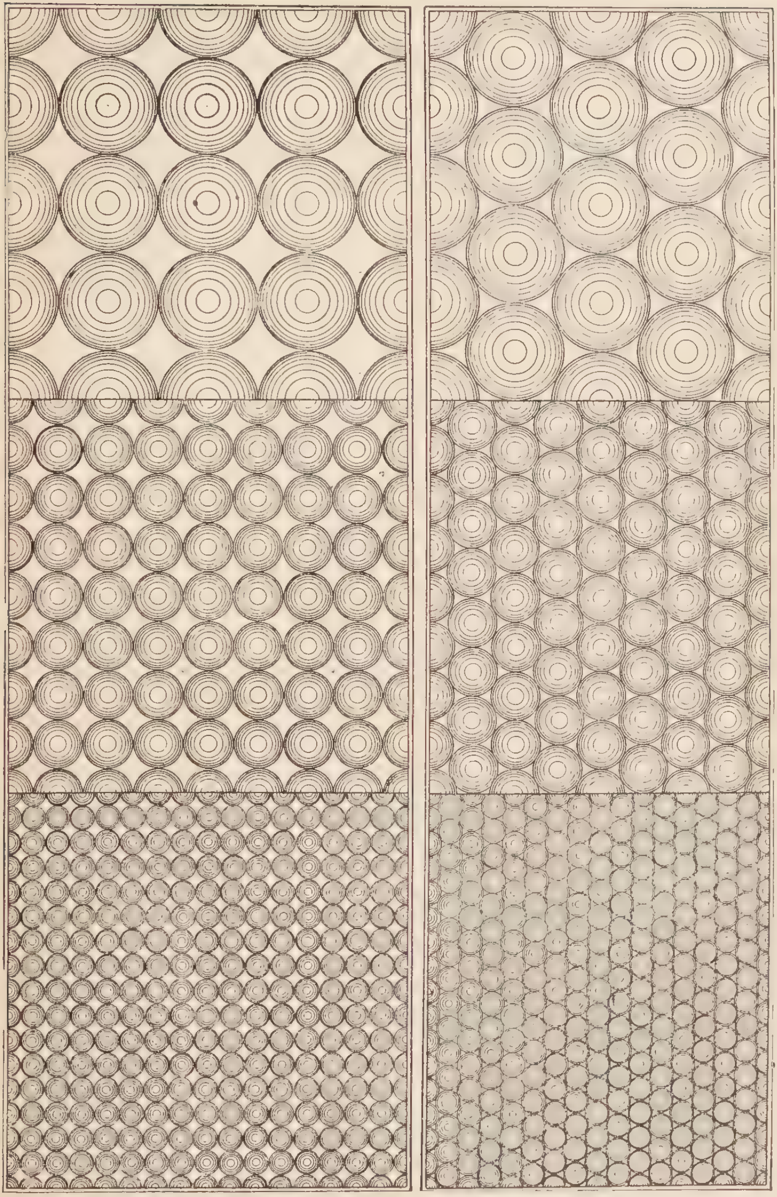


FIG. 20. Relative size of the largest pools.

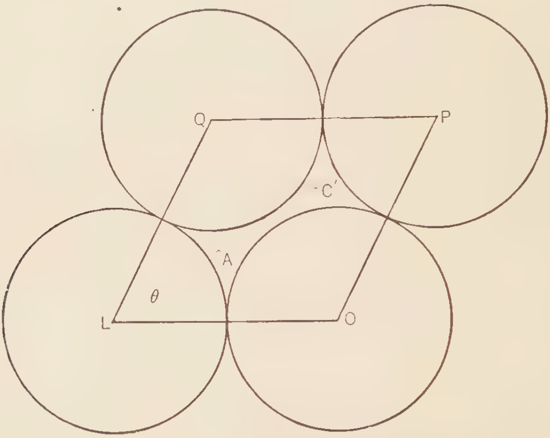
Porosity. — The porosity of a sandstone will vary with a number of factors. For instance, spherical grains of uniform size (Fig. 21) will afford the maximum pore space between grains. A sandstone composed of grains of many sizes and of irregular shapes (Fig. 22) will be more compact — the smaller grains filling in the interstices between the larger.



U. S. Geol. Survey, 19th Ann. Rept., Pt. 2.

FIG. 21. Maximum and minimum pore space of spherical soil grains.

Clay or other fine sediments often clog the pores of a sandstone. Another common limitation to the effective porosity of a sand is calcareous or siliceous cement between the grains. In examining the drillings from a well, attention should be paid to such evidence, in order to aid in determining the limitations of the reservoir and the causes of these limitations.



U. S. Geol. Surv., 19th Ann. Rept., Pt. 2, p. 309.

FIG. 22. Section of four contiguous spheres in a somewhat open packing of a mass of spheres.

A distinction should be made between the theoretical porosity of a rock and its *effective* porosity. Owing to the fact that in many rocks a considerable proportion of the pores do not communicate, even though the theoretical porosity may be high, the yield is necessarily very low. A rock with very small pores cannot be drained of its oil content, even though such pores communicate, because of friction and where gas or water is also present because of capillarity.

There has been very little work done in testing sands as to their effective porosity, and such knowledge is so important that it seems very desirable that the United States Geological Survey or the Bureau of Mines should give us some accurate figures.

Carrl[1] determined that fragments of the Third Sand at Oil City, Pennsylvania, are capable of absorbing from 7 to 10 per cent of their bulk of crude oil, without pressure, and states that under pressure this would probably be as high as 12½ per cent. Bell in his estimate of the oil reserve of California considered 10 per cent of the oil recoverable.

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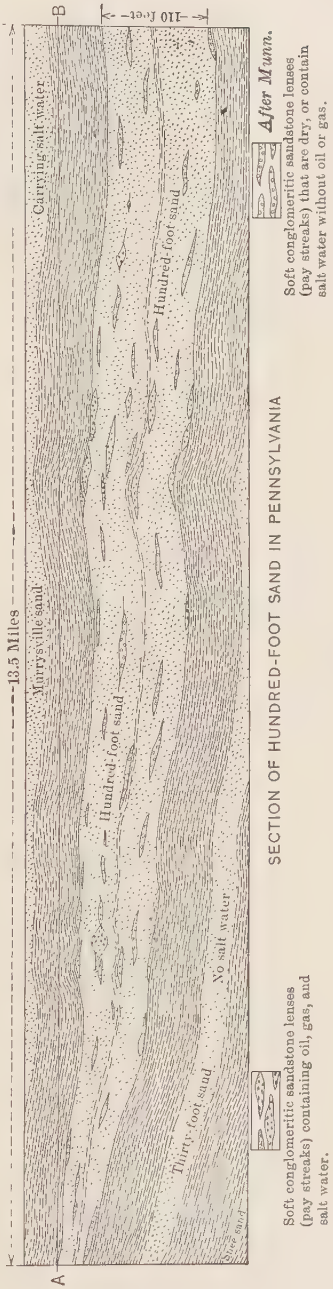
[1] Carrl, Second Geol. Surv. of Pa., Vol. III, p. 251.

This is quite different from Carrl's figure, for of the oil absorbed in Carrl's experiments, a considerable proportion would be held by capillarity and would not be recovered by ordinary producing methods.

Washburne[1] uses a saturation factor of 15 per cent for the average oil sand, but assumes that only 75 per cent of the sand underlying a large oil property or oil pool is saturated. Of this, he again assumes that from 60 to 75 per cent of the oil is extractible by ordinary producing methods. Capillarity must in most cases prevent a considerable proportion of the oil from being extracted (Fig. 25), and without gas pressure or gas or water replacement, most oil wells could not produce profitably. Thus we have the following equation for the Washburne estimates:

$$0.15 \times 0.75 \times 0.60 = 0.0675 = 6.75 \text{ per cent extractible.}$$

He admits that the last two factors must be varied to suit conditions. However, the 75 per cent saturation factor used is unsatisfactory, and should be accounted for in other ways. While certain properties where conditions have been unusually favorable may produce oil at this rate, which means 524 barrels of oil per acre-foot of *producing* sand, yet it may be mentioned that the phenomenal Glenn Pool in Oklahoma will probably not have produced more than 535 barrels per acre-foot of producings and at the


B
110 feet
A
13.5 Miles
Carrying salt water
Murrysville sand
Hundred-foot sand
Hundred-foot sand
No salt water
Thirty-foot sand
Stray sand
Soft conglomeritic sandstone lenses (pay streaks) that are dry, or contain salt water without oil or gas.
Soft conglomeritic sandstone lenses (pay streaks) containing oil, gas, and salt water.

After Munn.

SECTION OF HUNDRED-FOOT SAND IN PENNSYLVANIA

FIG. 23.

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[1] "Estimation of Oil Reserves" (Bull. American Institute of Mining Engineers, February, 1915).

time of abandonment. Few pools producing from Paleozoic formations or older have as favorable conditions as the Glenn Pool.

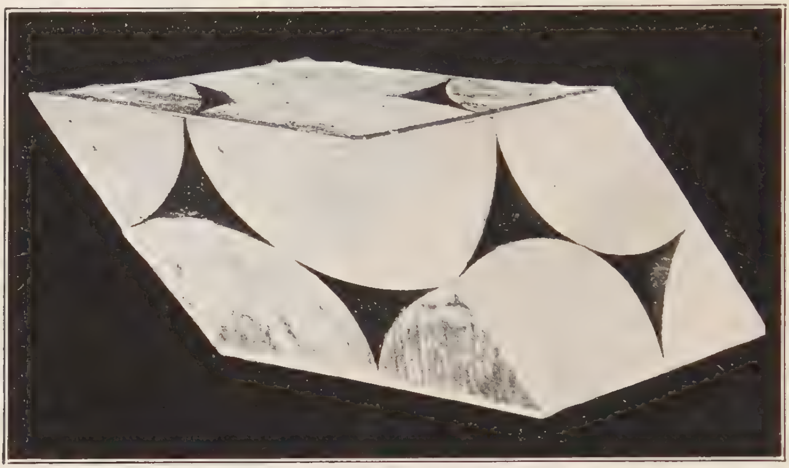

FIG. 24. To show interspaces between spheres. After King.

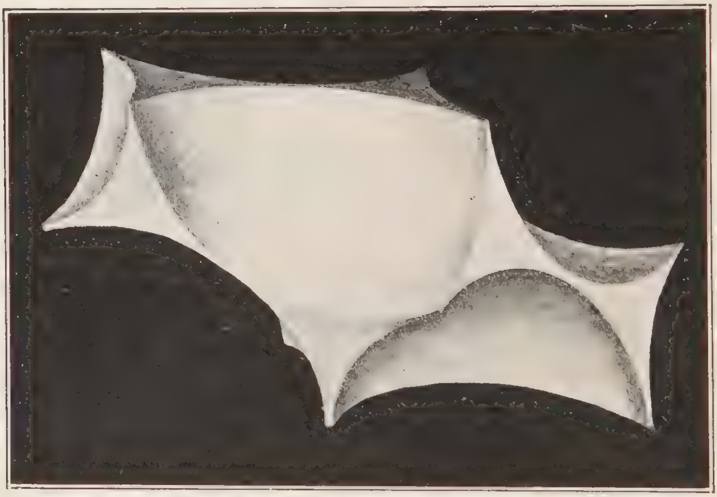

FIG. 25. Cast of the interspaces shown above. After King.

A. Beeby Thompson[1] assumes a saturation of 25 per cent for the oil sands in the Baku fields. Certainly the production of some of the producing properties warrants this, and the character of these unconsolidated sands is apparently such that extraction is much more efficient than in the older fields in the United States. Such fields are comparable with certain of the California pools in the United States. Not only is the effective porosity higher than in consolidated sands, but the sands are more uniformly saturated and water replacement has frequently effected unusually efficient extraction. However, applying Washburne's equation to a 25 per cent saturation we have:

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[1] Thompson, A. Beeby, The Oil Fields of Russia.

$$0.25 \times 0.75 \times 0.60 = 0.1125 = 11.25 \text{ extractible.}$$

Thus it will be seen that Bell's[1] estimate of 10 per cent may be conservative for California, while it would not do at all for the Eastern fields in the United States. In the Appalachian and Mid-Continent fields we may assume an average effective porosity of 10 per cent, and assuming that similar conditions prevail which would make Washburne's equation again applicable, we would have in the average pool

$$0.10 \times 0.75 \times 0.60 = 4.5 \text{ per cent extractible.}$$

Calculation shows that there are 7758 barrels of sand in a bed one foot thick and an acre in area; so assuming 15 feet of pay sand,

$$0.045 \times 7758 \times 15, \text{ or } 5236.55 \text{ barrels per acre.}$$

McLaughlin shows the following actual yields in California for wells not yet abandoned.

MIDWAY-SUNSET FIELD, CALIFORNIA

Average thickness of sand.	Area per well.	Production per acre.	Production per acre-foot.	Producing period.
Feet.	Acres.	Barrels.		Year.
87	10	2,751	32	3
118	5	60,074	510	3
136	4	15,127	111	5
160	9	11,656	73	3
189	8	3,464	18	3
117	5	17,952	153	$3\frac{1}{2}$
289	3	13,747	47	$2\frac{3}{4}$
186	5	10,331	55	$3\frac{1}{4}$
16	7	16,324	1020	$3\frac{1}{4}$
42	6	17,243	410	$2\frac{1}{2}$
75	7	12,715	169	$2\frac{1}{2}$
29	10	3,842	133	$2\frac{1}{3}$
147	3	11,044	75	3
94	5	15,504	165	4
140	4	24,882	177	5
72	4	37,589	522	$3\frac{3}{4}$
127	8	8,471	67	4
23	10	11,727	510	3
142	2	22,633	160	6
64	10	8,774	137	4
135	4	7,892	58	6
92	8	8,965	97	5
99	9	5,160	52	$3\frac{3}{4}$
93	3	15,757	170	5
40	4	6,583	164	5

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[1] Bell, A. F. L., Trans. Amer. Soc. Mech. Eng., Vol. 33, pp. 27–31.

WHITTIER-FULLERTON FIELD, CALIFORNIA

2.3 acres per well

COALINGA[1] FIELD, CALIFORNIA

Average thickness of sand.	Area per well.	Production per acre.	Production per acre-foot.	Producing period.
Feet.	Acres.	Barrels.		Year.
73	8	12,600	173	6
117	10	3,000	26	3¾
....	12	4,500	....	5
85	7	6,000	70	5
118	3	8,650	73	4
105	5	....	....	2½
121	5	26,900	222	6
80.3	6	31,300	390	8
59	13	6,200	102	6
57	4	47,800	840	5½
95	4.3	22,200	233	8¼
133	10	13,600	103	3½
110	8	10,700	98	....
95.5	8	22,800	240	....
106.8	3	74,400	700	....

However, some properties are flooded prematurely, in some the pressure is prematurely exhausted by neighboring wells, in others the wells are not managed properly, and many other local conditions affect the yield of oil. Also it must be said that sands vary in their effective porosity and no average value can be given which can be used generally. The most that can be done is to give maximum and minimum values for these different factors. The operator or appraiser must then take such values in connection with all he can learn of underground conditions and yields of the property in question as compared with others in the same field or where the various factors are similar. While local conditions may affect the yield of certain properties adversely, it should be understood that other conditions may make it possible for a certain property to produce at a higher rate than the surrounding pool. Among these may be mentioned the setting up of drainage channels in the sand, artificial channels caused by shooting, unusually porous beds of conglomerate in the sand, or the use of compressed air and various other methods to increase extraction to be discussed later. Such conditions or practices should be understood and due allowance made for them in all estimates of porosity or probable yield of an oil property or pool.

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[1] McLaughlin, R. P., Petroleum Industry of California, Calif. State Mining Bureau Bull. 69, pp. 267–287.

The following table shows the effective porosities of various building stones, as determined by E. R. Buckley.[1] These results were obtained by measuring the quantity of hot water taken up by the dry rock:

	Limits.	Average effective porosity.
	Per cent.	Per cent.
14 samples granite	0.108 to 0.519	0.332
11 " limestone	0.53 to 13.36	4.43
16 " sandstone	4.81 to 28.28	14.46

It will be readily seen that the possibility of oil reservoirs in igneous rocks such as granite is very slight, even though other conditions might be favorable. Limestone varies so much in porosity, and the average is so low, that while some limestone beds contain more or less oil, they do not yield their content readily upon being penetrated by the drill, unless they are unusually porous, dolomitic, fissured or jointed. The fractured and channeled Tamasopa limestone in the Mexican fields has given such enormous yields from single wells, under such unusual geological conditions, as to preclude any possibility of predicting as yet what the final yield will be from any given acreage or group of such wells. Certainly these fields cannot be compared with those producing oil from sand strata.

It is important to distinguish properly between the terms sand, sand body, reservoir, pay and pool, which will be used in a specific sense in this book, but which are in general used so loosely as to result in confusion.

Sand to the oil producer is unconsolidated sand or sandstone. It is sometimes objectionally used more widely to describe any formation which yields oil or gas when penetrated by the drill.

Gas sand is sand which when reached by the drill contains gas in appreciable quantity and pressure. Oil sand and water sand are used for sand yielding oil or water respectively. If one sand-body contains gas, oil and water in different parts, these several parts are called gas, oil and water sands, irrespective of their lithology. That there is a characteristic lithology for each of these three sands and that one sand body contains only one of the three is a common, erroneous belief. Oil men entertaining this notion explain the exceptional cases, that are so common, by assuming that the sand is divided by a break or shell.

A sand-body is one continuous mass of sand or sandstone.

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[1] Buckley, E. R., "Building and Ornamental Stones of Wisconsin."

A reservoir is a system of communicating interspaces of such diameter and so connected as to yield gas, oil or water to a hole penetrating it.

The oil pay is that part of a reservoir that can yield oil in commercial quantities. The gas pay, similarly, is that part that can yield gas.

A pool is that part of a pay thick enough to yield its product in commercial quantities. It may be used to describe the actual pay or the area at the surface underlain by it.

The enclosing beds of the reservoir. — The word "cover" has been used, in this connection, referring usually to the overlying beds, by those who seem to imply that the contents of the reservoir have far greater pressure than the surrounding formations, and especially more than the overlying beds. As a matter of fact, the difference in pressure is only slight. Neither is the word "impervious" properly used to describe the adjacent rocks, as oil and gas have usually found their way into the more porous reservoir from the surrounding shales by the process of selective segregation, and such shales are still frequently somewhat petroliferous, and generally water wet both above and below. Being of finer texture than the oil or gas reservoir, they do not give up their contents as readily as the more porous medium does, and as they contain little or no gas, it takes longer than is allowed for the closed pressure of such beds to become fully evident at the gage. The imperfect means of measuring the static pressures existing in the formations, unless there are large volumes of gas or oil present, gives erroneous ideas of an erratic variation in underground pressures. Certainly, if the fluid contents of certain beds have a more direct connection with the surface through an outcrop or some other passage, the pressure equilibrium will be more disturbed, but the difference will be taken up and distributed throughout the surrounding formations and not be particularly marked between adjacent beds. But such conditions are comparatively rare in oil and gas fields, and the difference in pressure is less than is usually supposed.

According to the nature of the process which caused the concentration of the oil and gas in the reservoir, as discussed in Chapter V, the strata surrounding an oil or gas-bearing sand-body will come under one of the following heads:

(*a*) Water-wet fine rock.[1]
(*b*) Closely cemented sandstone.
(*c*) Very fine rock (shale, slate, marl, compact limestone, etc.).

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[1] Day, D. T., Science, n. ser. 17 : 1007.

The termination of the reservoir. — An oil and gas reservoir may terminate laterally in a number of different ways, which may be grouped under the following heads:

1. Lenticular.
2. Differential cementing.
3. Fault.
4. Intrusive.
5. Paraffin or asphalt sealing.

1. *Lenticular.* — The sand-body may be merely a lens included within shale beds or other formations such as occur in the Third Sand horizon in Pennsylvania. In fact, most of the oil and gas pools of the world are of this nature. The Bartlesville sand is a name given to a horizon consisting of a series of more or less restricted sand-bodies which " tail " out and are essentially lenticular. This is true of most of the Oklahoma sands. Others do not taper off but the whole reservoir gradually becomes less porous, and are more properly called disks. Still others have shapes as in Fig. 26. On the other hand, a few instances are known in which the sand-body of uniform thickness and porosity covers such a wide area as to be given the name of a "sheet" sand. The St. Peters sand is a good example of this, as well as the Dakota sand of the Northwestern Plains fields.

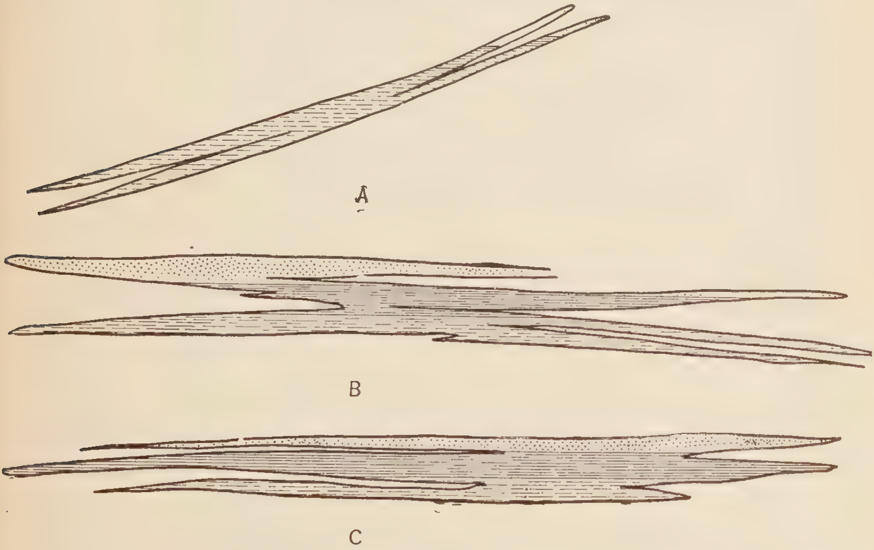

Fig. 26. Gravitational sorting as influenced by the shape of the reservoir in a vertical plane. Dots = gas, lines = oil, broken lines = water.

2. *Differential cementing.* — Within a sand-body some parts are more porous than others or, though equally porous, some parts have more effective porosity, usually because the pores are larger. Sometimes this is due to beds of coarser sand or conglomerate included within a finer matrix. But frequently portions of the sand-body have their grains cemented to an unusual degree by calcareous or siliceous cement. Such cemented portions sometimes follow bedding planes and the cementation has been caused by original lithologic differences. In other cases the cementation is more irregular. This is one of the causes of what is known as a "tight" sand. Frequently beds of such cemented sand separate the various "pays" in an oil sand. When broken up by the drill, this cement may not show except by close examination with a microscope.

3. *Faults.* — Faults act in three general ways to form oil reservoirs: (*a*) if there has been sufficient throw to offset the fault surface of a sand-body containing oil against formations through which oil does not pass readily, the oil is held against the fault surface as a barrier.

(*b*) If the faulting at the same time plastered the walls of the zone with clay or impervious material, even though the amount of the throw was slight, oil tends to accumulate below this gouge as below a barrier.

(*c*) If the fault remains open, such a fracture may allow migration of oil from lower porous beds to higher, and a greatly faulted sheer zone itself may effect an additional concentration of oil.

4. *Intrusives.* — Intrusives act in a similar manner to faults, which they sometimes accompany. If they reach the surface, however, they act in a further manner to prevent the faulted formations from pinching together, and as they usually contain shrinkage and joint cracks these offer a means of egress for the oil, which exudes at the surface as an oil or asphalt seepage.

5. *Paraffin or asphalt sealing.* — The term paraffin is here used to describe the light colored waxy material which is the heaviest portion of the paraffin oils. These oils are especially characteristic of the Eastern and Wyoming fields and of certain of the Mid-Continent pools. This substance is a solid, and when a crude oil containing it is cooled below a certain critical temperature it separates from the rest of the mixture as a cloudy amorphous sediment, which settles to the bottom. When such a crude oil loses a certain percentage of its lighter hydrocarbons, the same effect is noticed. Wax may form at the sand face and fill up the tubing, either stopping or seriously impeding further production.

Asphalt is the term generally applied to a black material made up of carbon and hydrogen with either sulphur or oxygen or both. It is found in most of the heavy California, Gulf Coast and Mexican crude oils. It frequently accompanies the paraffin wax in the Mid-Continent oils. It is generally a mixture of solid and semi-solid compounds, so that a slight change in temperature may cause even the solid asphalt to flow. It does not separate from the rest of the oil when the temperature is lowered, and gives no trouble from waxing up the sand face or the pumping rods in wells.

Oil is found in the California fields in wells drilled but a short distance from seepages of asphaltum, which seal the outcrop of the sand. As most of the oils found in the younger Tertiary formations are asphaltic, and as most of the known examples of such accumulations back of sealed outcrops occur in these formations, it has been argued that such oils are more efficient in sealing[1] the outcrop than are paraffin oils.

Most of the paraffin oils occur in older rocks, principally in the Paleozoic and Cretaceous. In these older rocks the contents of the underground reservoirs have more nearly reached a state of equilibrium, and erosion has had much greater opportunity to destroy all evidence of oil accumulations near the original outcrops. There is evidence, from wells producing paraffin oils from these formations, that paraffin frequently forms an excellent and most effective seal,[2] so far as stopping production is concerned. It may be possible that as the asphalt oils lose their lighter constituents they become gradually more viscous, and finally a large mass of this viscous "tar" offers enough resistance to prevent further oil being lost. The paraffin oil after losing more and more of its lighter constituents reaches a point of saturation when it deposits paraffin. This deposit may extend some distance back from the outcrop, and be much smaller than the great mass of inspissated "tar" which collects at the outcrop in the case of the asphaltic oils. It is far less noticeable because of its light color.

While the present asphalt-sealed outcrops are much more obvious, there is evidence that paraffin may be an efficient agent in attaining the same result. The early shallow wells drilled in Pennsylvania were near the outcrops of the Venango oil sands, and oil springs at the surface led to the discovery of the first wells. More recently, the paraffin oils in the San Juan field in Utah are found back of an outcrop showing oil residues.

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[1] Pepperburg, L. J., Western Engineering, May, 1915.

[2] Carrl, J. F., Second Geol. Surv. of Pa., Vol. III.

CHAPTER V

THE ACCUMULATION OF OIL AND GAS

Oil and gas must arise either at the point where found or else move there from the point of origin. Probably there are no authors who would assert the immobility of oil and gas. Yet there is a division of opinion among students of oil and gas, some maintaining that the oil and gas found in a porous reservoir arise somewhere in that reservoir, and others who think most of it has found its way there from without the reservoir.

The endogenous view is based upon the alleged imperviousness of the surrounding material of the reservoir, which would prevent the entrance of any water, oil or gas, and so leave no other origin than an endogenous one possible.

A serious difficulty with the theory of the endogenous origin lies in the fact that, in sandstones, organic matter breaks down rapidly, largely into carbon dioxide, so that it is seldom that the analyses of fossiliferous sandstones yield appreciable quantities of organic remains, in spite of the fossils which consist merely of limy shells or even of mere impressions or casts. On the contrary, in accumulating muds, especially in salt water, decomposition is retarded, apparently on account of the arrest of a ready circulation of water carrying oxygen in solution. There is a complete intergradation between sandstones and shales. In fact, shales which are more or less sandy are more common than purely argillaceous shales. Since practically no sedimentary rocks are non-porous, and since the permeability of resistant rocks varies markedly with pressure, we may conclude that, with time and high pressure, a slow motion of fluid through wet rocks is possible in a larger percentage of sedimentary rocks than has been supposed by the authors who favor the hypothesis of the endogenous origin.

The barrier to the movement of oil and gas, constituted by a water-wet fine rock, is adequate to hold back oil and gas, even though it might not be absolutely impervious. Indeed, water might be slowly rising in it while it was acting as a barrier.

Assuming, then, that oil and gas arise predominantly in shales, we

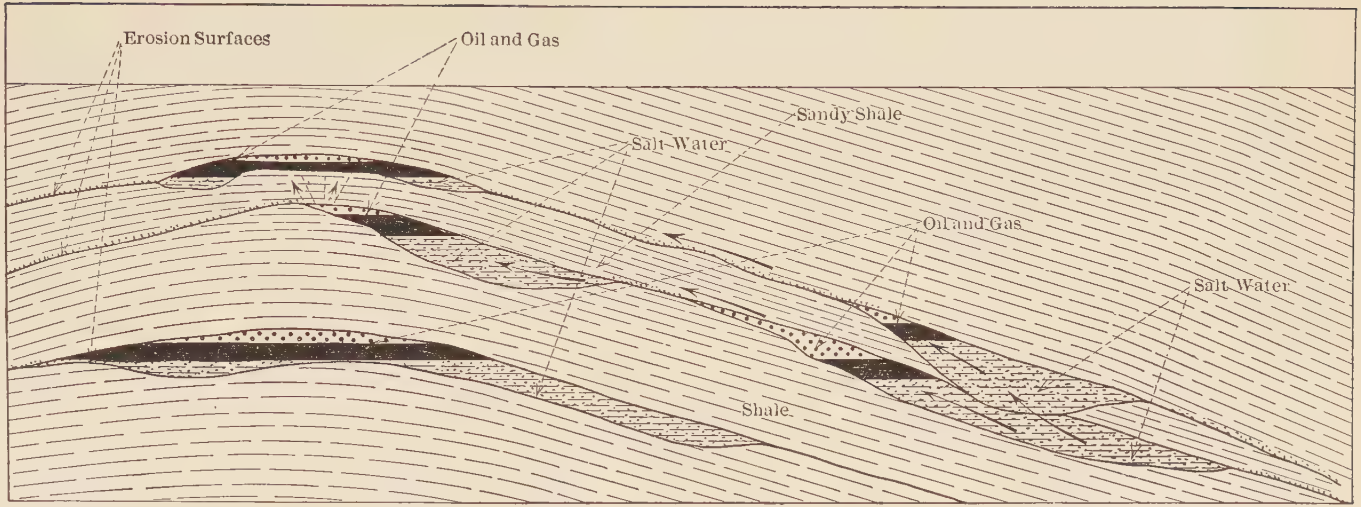

FIG. 27. Idealized section through a dome showing sand-filled channels in cross-section, points of accumulation of oil and gas, and direction of migration. Modified from Wallace Lee, Illinois Geol. Surv. Bull. 31.

are next concerned with the cause of its movement. The leading cause is the compacting of the strata by the weight of the gradually increasing overburden. Freshly laid muds before being compacted by superimposed beds have a very high water content, higher even than the associated sand deposits. Compacting is vastly more effective upon the mud, reducing it to relatively dense shales, than upon the sand that is not capable of equal reduction in volume. The expressed fluid moves from points of maximum compacting to those of minimum compacting.[1] Much of this movement is upward, since the compacting increases with depth. Some of it is along lines of less resistance, such as sandstone members (Fig. 17), in the direction where the overburden is less heavy, either because of lighter or thinner material.

Important as this factor of compacting is, its principal activity is limited to a relatively short period, since most of the compacting is accomplished as soon as the grains are brought into close contact. There is a second stage of compacting, not reached till very long thereafter, when the pressure becomes so great, in the zone of rock flowage of Van Hise, that the pores previously left are now again greatly reduced in number and size. This action produces a flow of the fluid and gaseous contents in general upward.

While this statement is made thus clean-cut for the sake of explanation, in reality there is not such a distinct and regular increase of compacting as the overburden accumulates, owing to the variability of different rocks in composition and in texture.

A second cause of movement is the increasing temperature as rocks become covered to a greater depth, since rock, liquid and gas expand at different rates. The expansion of fluid and gas is so much greater that they must be forced in general upward.

The third cause is the pressure produced by the formation of new dynamo-chemical gas, as the depth increases, and the heat and pressure correspondingly. The deeper coals show a loss of hydrogen, indicating the formation of CH_4, which is actually found with the coal. In the eastern fields there is an apparent increase in the proportion of gas to oil and water with depth.

The fourth cause is the reduction of the volume of voids by the deposition of cement in the pores of rocks undergoing consolidation. This must force out the fluid or gas previously occupying this space. This cementation increases as the rock becomes deeper and deeper by the accumulation of overburden, since deposition is greater from deeper waters, because of their greater load of dissolved material.

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[1] Daly, M. R. The Diastrophic Theory. Amer. Inst. of Min. Eng. Bull. 115, pp. 1137–1157.

The fifth cause is the oscillation in depth. All parts of the earth's crust are not being gradually overlaid at the same rate. In fact, over a small area the overburden remains practically the same, over another area it is being gradually removed. From time to time any particular area passes from one of these conditions to another. Many reservoirs may thus oscillate in altitude, in relation to sea-level, several times in their history. As we shall see later when discussing causes of pressure, this oscillation of depth (Fig. 28) produces an oscillation in both the pressure and temperature of the reservoir. Now, since the rate of expansion of gas and of liquid is different, such changes in elevation produce a change of level of liquid within the reservoirs.

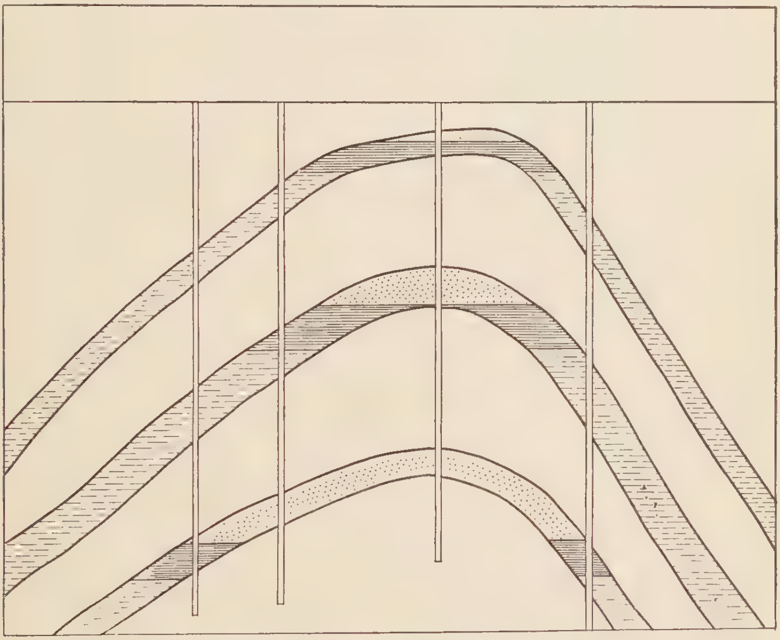

FIG. 28. Relation of oil to gas as modified by depth and asymmetry.

The sixth cause of motion applies only to shallow depths, except in sheet reservoirs of very considerable lateral extent. There is a flow of surface water through the reservoir or a series of connecting reservoirs from higher to lower levels, where the water emerges at the surface.

A seventh cause of motion is the breach at the surface by erosion or at some depth by a fault, which permits the escape of the lighter oil and gas at first from relief expansion. Later the oil and gas is extruded by the entrance of water which being heavier accumulates at the bottom of the reservoir and so gradually lifts the oil up to the point of exit.

The liquid and gaseous contents of the muds or rocks containing organic detritus for these various reasons are forced to move from pore to pore. The reservoirs, as paths of least resistance, especially where the dip is high, become highways for the passage of the oil, gas and water that were in the muds. This motion is predominantly upwards. Since the beds are of such a varying nature, and are more frequently of low dip than high dip, it must move laterally through a great deal of its course. This course is, nevertheless, more ascending than lateral in most deep-sea beds of considerable thickness. It is predominantly descending in the zone of strata which have been lifted above sea-level and now carry fresh or brackish waters, and this is especially true in all parts of sheet sands lying above the lowest exposure.

Method of segregation. — But this material moving through reservoirs has too small a content of oil or gas to be commercial. If segregation could be effected by which some of this oil and gas could be retained in the reservoir, while the water passes on, then we could explain these commercial deposits.

There are three agencies that would act in this way:

(1) *Capillarity.* — The capillarity of the liquid gives it so firm a grip upon the surrounding small pore rock that the gas in the large pore reservoir cannot ordinarily force its way through. Similarly, though in a much less effective way, the lower capillarity of oil tends to retain it in the larger pores where the current is from the larger pores into smaller ones.

(2) *Immiscibility.* — Since the surrounding rock is water-wet with only diffused bubbles of gas and oil, it is more difficult for the oil to pass through owing to the immiscibility of the two liquids. Thus while oil does not readily flow through a water-wet porous cup, it is also true that water does not readily move through an oil-wet porous cup. The reason is that the entering fluid rounds off into bubbles, which of course can less readily move through the occasional restrictions of the channel. In addition, immiscibility prevents the intermingling of the two liquids, water and oil, which otherwise would by this means circumvent the action of capillarity already mentioned.

(3) *Relative viscosity.* — In spite of the great reduction of viscosity due to the higher reservoir temperatures as compared with room temperatures, some petroleums are still appreciably more viscous than water at these temperatures. The resistance of small pores is much greater

to viscous oil than to the less viscous water. This is especially true since immiscibility prevents such an intermingling as would break down this difference.

These three agencies work together so intimately that it will be convenient to combine them in the phrase "selective segregation." This may be defined as the process taking place in the passage of a mixture of gas and liquid, or of oil and water, from a relatively more porous to a less porous rock by which process the gas and the oil are more retarded than the water.

We find, then, a gradual segregation of the oil and gas in the reservoirs which have their water content gradually displaced. The gas is probably more effectually segregated than the oil, some of which passes on, the amount depending upon the temperature, the kind of oil and the absolute and relative size of the pores of the two kinds of rock.

The formation ordinarily becomes deeper and deeper as more overburden is added. As this takes place, the rate of compacting of the formations is soon so much reduced that thereafter the flow becomes less and less. The flow is less not only because of this lessened impulse, but also because of the greater resistance. Any oil and gas thus moved could only be the original bio-chemical oil and gas. But when a certain depth has been attained, where the pressure or heat becomes adequate, the dynamo-chemical oil or gas or both are produced.

In so far as gas is formed it has an important effect in increasing the pressure and so in increasing the upward movement of all the contents. It also more rapidly fills the reservoirs, displacing more of the fluid. In fact, it is highly probable that, given enough organic detritus in the adjacent formations, the reservoirs are completely gas-filled at depths from a mile down to the "zone of flowage." For this reason we believe that by means of deep drilling, gas fields will become more widespread than oil fields.

Gravitational separation. — The fact that gas, oil and water in a bottle become arranged in the order of their specific gravity has had a great influence in the history of our ideas on the accumulation of oil and gas. But we are dealing with material in a porous rock, where there are two limitations to this vertical separation.

(1) It does not take place in porous bodies finer than a certain critical degree because of "capillary interference," and (2) within certain limits of porosity, embracing most of the productive sands, it takes place only as the contents move. Fortunately there are usually adequate means of motion.

The vertical separation, important in itself, becomes of especial importance when we consider the fact that most oil reservoirs are more or less lens shaped, and that this lens is generally tilted more or less from the horizontal. This inclined plane produces lateral motion, so that wells drilled in the lower part of the reservoir may yield water only, in other parts oil above water, and in still other parts, oil from the top to the bottom of the sand. The usual figure to represent this condition has the dip and the relative thickness of the bed so much exaggerated that an erroneous impression is created. In Fig. 29 a common condition is drawn to scale. Yet even this is steeper than the average pool. This lateral motion might be assisted by the upward flow of the liquid contents of the reservoir, but such motion is so slow as to be generally ineffectual. We have, then, the gas mainly at the upper side of the reservoir.

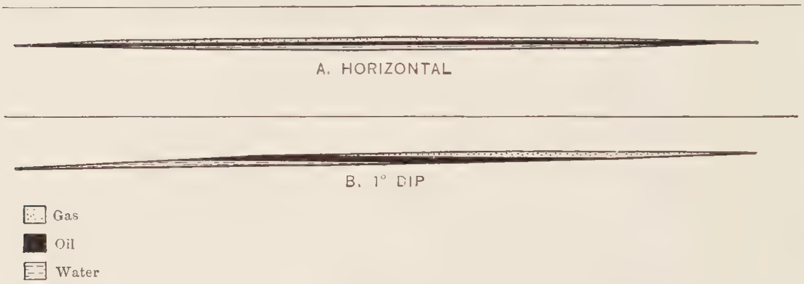

Fig. 29. Showing effect of gravitational separation with low dips.

Even where the reservoir has not been tilted from the horizontal, the roof so frequently departs from horizontality, especially at the edges, that this depositional gradient is sufficient to produce similar lateral motion, and hence an accumulation of gas and oil.

Application of Gravitational Separation to Folds

Oil and gas bearing reservoirs are found in general in unmetamorphosed sedimentary rocks. They occur in (*a*) folded beds and in beds with (*b*) no dip, (*c*) on plane-dipping homoclines, or (*d*) on folds. Since folds in the reservoir are in many cases also more or less evident in the surface formations, any influence they might have upon accumulation is of especial importance, since they can be observed. This relationship, rather than any greater frequency of reservoirs on folds, has led to such a disproportionate amount of attention to folds, even to the wholly unwarranted statement "all oil is found on folds."

When we consider the effect of folds, the important determining conditions to be distinguished are (*a*) whether the reservoir is large enough to extend across the axis of a fold for if not, the reservoir is merely homoclinal; (*b*) whether it is plane dipping or whether there is a critical change of dip; (*c*) whether the reservoir lies so high on the fold as to be exposed at the crest.

It is the form of the roof, or in cases where there is no water, then the floor of the reservoir, not its mid-plane, that gives it effectiveness. This is the result of depositional as well as deformational gradients or dip. The gradients will therefore be treated, whatever their origin, in the chapter on classes of attitudes.

Such depositional gradients in the roof of the reservoir (*a*) may have such a direction and degree as to neutralize any accumulation made by the agency of the deformational gradient of the bed as a whole, or (*b*) may reverse the gradient, or (*c*) may accentuate such accumulation. Where the dips around a favorable structure in outcropping beds are very gentle — less than five feet in a thousand — there is great danger that lack of parallelism may prevent the repetition of the same favorable structure in the reservoir directly below. This danger becomes progressively less as:

1. The convergence is less in amount.
2. The convergence is less regular.
3. The depth is less.
4. The outcropping bed that is used is more extensive.
5. The outcropping bed that is used is more regular in thickness.
6. The dips are greater.

The reduction in promise of promising structures from this cause is generally under-estimated, yet they remain superior to regions of plane-dipping beds in spite of this severe drawback.

CHAPTER VI

THE PRESSURE IN OIL AND GAS RESERVOIRS

Oil and gas are invariably under pressure in reservoirs which are not exposed or exhausted. This pressure increases roughly with depth, but with decided variations. To understand the rate of this increase and the reasons for these variations the several causes must be discriminated.

The pressure is the result of two sets of conditions, one of which directly increases the pressure, called here the additive factors, and another set which maintains the pressure by preventing its relief by expansion.

Additive Factors

(*a*) The production of new gas in or near the reservoir by any agency, since this would occupy more space than the material from which it was derived.

(*b*) Accession of additional gas from below, whence it had been occluded by (1) the closing of pores from rock flowage, or (2) melting of rocks by encroachment of igneous intrusions, etc.

(*c*) The reduction of the volume of the reservoir by the deposition of cement.

(*d*) When the reservoir communicates with the surface and is unusually porous, then the weight of the column of water.

Resistance to the Relief of Pressure

The foregoing factors would not be effective if there was an opportunity for the given volume of gas to expand and thus obtain relief. This relief is obtained if the pressure becomes high enough to overcome the resistance. We next consider, therefore, these elements of resistance:

(*a*) Resistance by capillarity is offered to the flow of liquids through a very fine porous medium which contains gas or an immiscible liquid. This applies also to the movement of gas through such a medium, containing more or less liquid.

(*b*) Friction.

(*c*) The porosity of parts of the column is so fine in most cases as to prevent the downflow of the surface water. While this prevents the weight of the column of liquid from being an active factor in producing pressure, yet this weight is effective in preventing the escape of any oil or gas, unless its pressure is greater than the weight and the other factors of resistance.

In practice the rate of decrease is not so irregular but that the depth times a given factor (which differs with the fields) may be used in roughly predicting the pressure. The effort has been made in several cases to show that this factor is that of the weight of water, and that therefore pressure is determined solely by the hydrostatic factor. The adherents of this view have resorted to such different expedients in order to make theory approach fact, that we may discredit it. Orton in dealing with the Trenton of Ohio measured from the outcrop on Manitoulin Island in Lake Superior, with an elevation of 600 feet, whereas this island is in Lake Huron with an elevation of 581 feet. On the other hand, Washburne contends the results are more consistent by calculating from the depth of the well. Again, whereas Orton uses a column of water with a weight of 0.476 pound per square inch for a column a foot high (that of well water), Phinney[1] uses 0.437½, and Hager 0.434, a nearly pure and a pure water respectively. None of these figures is correct, because the column of water varies in weight from 0.440 to 0.572 pound from field to field, and in any one field varies in density with depth, being nearly fresh at the outcrop and denser than sea-water at the bottom of the well. If we recalculate Orton's problem using such an intermediate value, his figures, that seemed so close a fit to the facts, are wide of the mark.

The "closed" pressures recorded by Phinney seem to have been recorded after the wells had been producing for a while, yet the infeasibility of any hydrostatic formula is evident from his report of the pressure in the Muncie Highland well, where an actual pressure of 320 pounds exceeded that which would be derived by Orton's factor by 65 pounds per square inch.

The hydrostatic method gives poorer results than the one to be described later, partly because it is dependent on data that is seldom obtainable. It is necessary to know the density of the water at the bottom of the well, and at several intermediate depths, in order that the correct weight of the whole column can be calculated. It is also necessary to know that the reservoir extends to the outcrop of that horizon, which is most frequently not the case. If the reservoir does not reach the surface, then the height of the surface above this end of the reservoir represents the top of the hypothetical column of water (Fig. 30).

But most reservoirs do not extend to the surface. To make the hydrostatic method applicable to these pools, we should have to take the vertical column of water, or better a zig-zag column of water, up the path of least resistance, and ending we know not where. The extent of the reservoir and the position of the path are unknown when the original reading at the first well is taken, so we would not know whether to take a vertical column to the lowest point of the outcrop, to the unknown top of the path of least resistance, or merely to the top of the well.

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[1] U. S. Geol. Surv., 11th Ann. Rept., Pt. 1, p. 663.

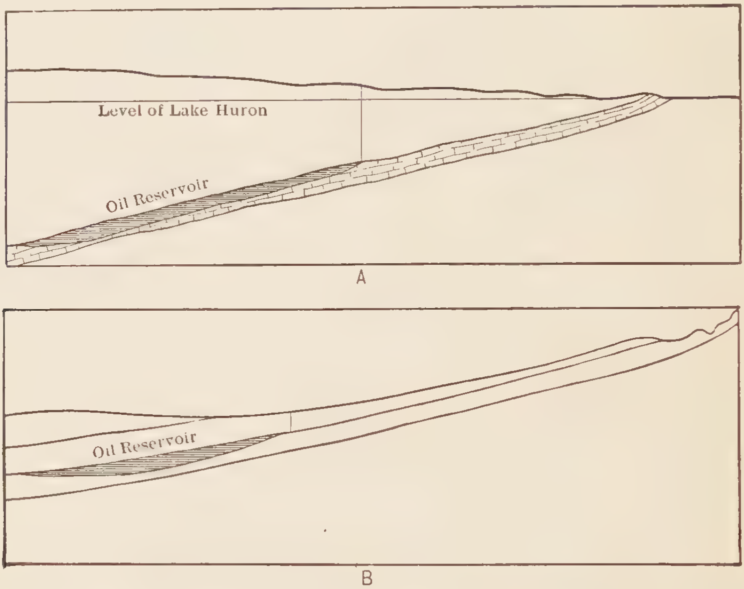

Fig. 30. To show that, where the reservoir does not extend along the horizon to the surface, the vertical column of water should be calculated from the upper end of the reservoir to the overlying surface. This may be higher (*A*) or lower (*B*) than the outcrop of the horizon. Vertical scale exaggerated.

The determination of pressure is a matter of the complex interaction of several factors, some of which cannot be definitely known. We must fall back then upon an empirical method, using the formula deduced from the most analogous field. If we wish to predict the pressure in a new reservoir, we ascertain the rate of increase with depth by the use of two ascertained pressures[1] at the points in the analogous field above and below the depth in question. The depth of each well is multiplied by this rate. The average deviation of these products from the observed pressure is calculated. We then have the data for the following formula:

$$\text{Pressure} = \text{Depth} \times \text{Rate} + \text{Deviation}.$$

[1] May we not hope that the United States Bureau of Mines will collect the data of the original pressure in many wells, before the records are lost?

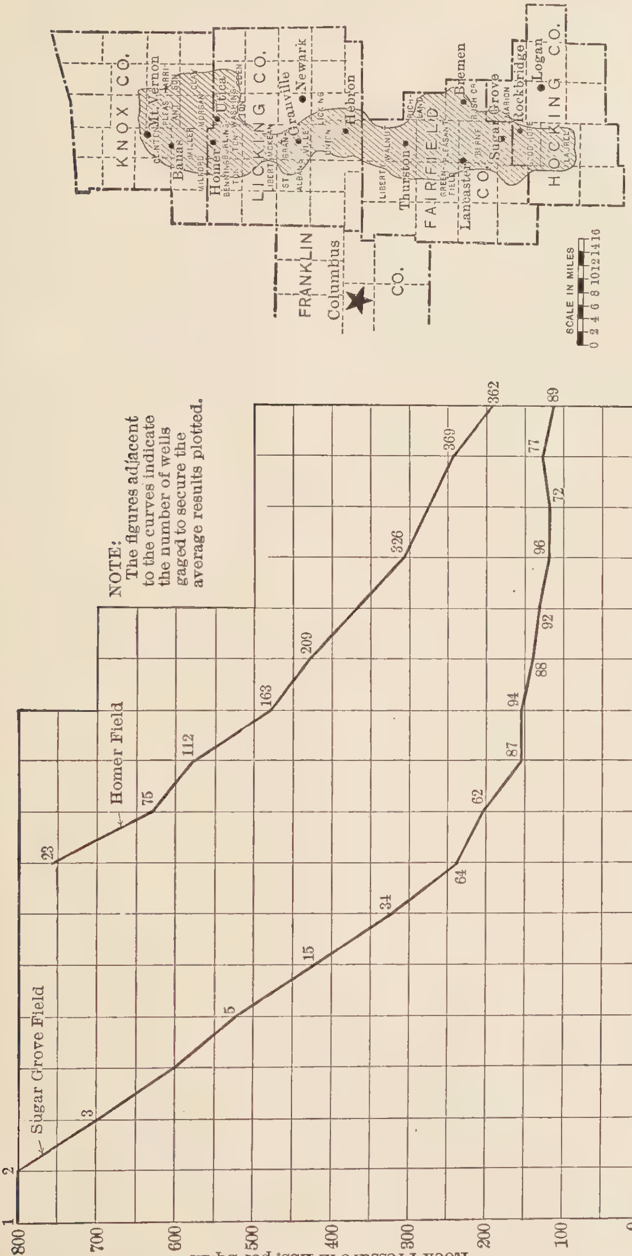

FIG. 31. Curves showing depreciation of natural gas wells in two typical fields in Ohio. (Courtesy S. S. Wyer.)

But when a gas well, the pressure of which is to be predicted, is in the same reservoir, or supposed to be, but not in the same pool with other wells, the pressure of which is known, then for actual depth substitute the depth from the average altitude of the wells. Thus in Orton's wells this is:

$$P = 0.48 \times \text{Depth from average altitude} + 41.$$

While the error is least with this method, it is necessarily large with any formula, because the result is that of the interaction of several independent factors and because the rate of increase changes with depth. Fortunately only rough estimates of the expected pressures are needed.

A common fallacy is the assumption that the pressure of gas is not uniform in one pool, but is highest at the crests of the anticline. The kinetic theory of gases necessitates a substantially uniform pressure throughout any one gas pay until its penetration by wells, which creates differences requiring a certain time for equalization.

If we have two reservoirs, one at the crest of the anticline and another far down the flank, the upper reservoir will have no higher pressure. On the contrary, it will be lower. There is no special pressure-making potency in anticlines. Even if there were, the pressure in such reservoirs would gradually reach the general pressure for its level in that vicinity, owing to the gradual upward creep of water which has an equalizing effect.

CHAPTER VII

THE ORIGIN OF THE SHAPE OF THE RESERVOIR

Before proceeding further it is necessary to distinguish between the words *sand-body, reservoir, pay, pool* and *oil sand* (Fig. 32). While too often used loosely, they should be distinguished as follows:

A *sand-body* is any body of sandstone lying in place.

A *reservoir* in the geological sense is that portion of a sand-body or other rock in place, with pores of sufficient number and size as to be capable of holding and yielding a commercial quantity of oil or gas if they are present. It includes the whole porous volume whether it contains water, oil or gas.

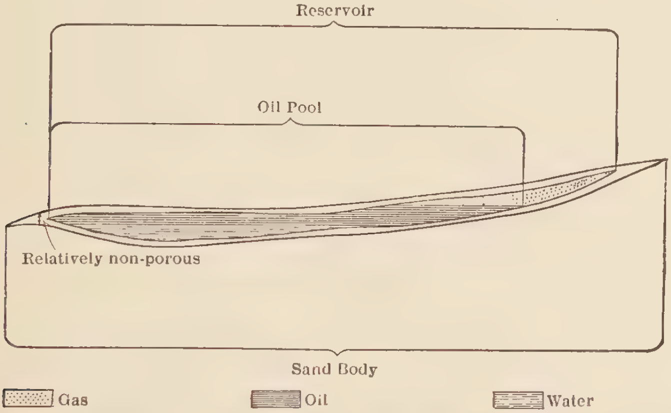

FIG. 32. Diagram illustrating the use of the terms "reservoir," "oil pool," and "sand-body."

A *pay* is the portion of such a reservoir containing the product in question — as the oil pay, gas pay (or if the water would pay to produce, a water pay). When used without a qualifying adjective, it means strictly oil pay, or gas pay, depending upon the recognized object of the operators, but less strictly it is used in the sense of oil pay.

An *oil pool* is that continuous portion of a reservoir containing oil. There may be several pools in one reservoir, separated by portions containing gas or containing water.

Oil sand is sand which contains oil in commercial amount, or did contain it when in place. Gas sand or water sand have the corresponding meaning with respect to gas or water. It is sometimes loosely used to characterize any sand that is adequately porous to be an oil sand, but this use is objectionable.

In describing the porosity of the sand, the terms *close* or *tight* for low porosity and *open* for high porosity, are to be preferred to hard, soft and loose, all of which are needed for other obvious specific uses.

The gradient of the upper and lower bounding surfaces of the reservoir concern us more than that of the sand-body as a whole. Of course the gradient of the bed, which contains the reservoir, is an important determining feature of the attitude of the two surfaces. The four factors which determine the attitude of the bed are the *surface of deposition, the distribution of deposition, tilting* and *folding.*

The surface of deposition is normally not horizontal, because the sands, which are to become reservoirs, are found on a sinking shore. The very fact that it is a shore and is sinking is evidence that it has inclination. There is not only a general inclination of the beds over which the sea transgresses, but there are deviations from a strictly plane surface as the result of (*a*) the drainage system, and (*b*) the varying resistance to erosion, since complete peneplanation is rarely realized.

In fact the shore line itself (or the inner shore line if there is a lagoon) on account of these factors is rarely straight. The straightness of many beaches lying outside of a lagoon does not belie this position, because the floor on which the sand rests was the inner shore of the lagoon, not the outer shore of an older, straight beach.

As the rate of subsidence differs along a coast line, there is not only a tilting but a change in the shape of the shore line and in the position of places of maximum sand accumulation.

Lastly, the beds receive a gradient from folding. This folding may be so slight, as to be better suggested by the word warping, or the folds may be numerous and irregular, or they may be well-marked and in general parallel.

So far we have considered agencies that affect the bed as a whole and hence necessarily its bounding surfaces, but we must not overlook — as is too frequently done — the gradient arising from agencies that affect only one of these bounding surfaces, but not the bed as a whole. This is important, for it not only affects the thickness of the reservoir but also the action of gravitational separation.

While the topography of the surface over which the sea transgresses affects the attitude of the beds as a whole, when the irregularities are not large the whole bed will not respond, but only the bottom of the bed, the regulating action of the waves giving a more even top to the bed. This irregularity of the bottom is also reduced, although to a lesser degree, by the regulating action of the waves, as they act more energetically on salient parts.

A second cause of irregularity of the bottom, which affects the shape of the bed as a whole and also the top, is the production of irregular interbedding of shale and sand by the currents in a lagoon, by the sweep of the tides in and out of the "guts," the current of incoming streams, and the currents caused by the adjustment of the tidal inflow and outflow at the different "guts." This action can be plainly seen from the deck of the shallow draught steamers plying between Babylon, Long Island, and Fire Island.

A reservoir is by no means an entire body of sandstone. The following portions do not act as reservoirs:

(1) Parts having the interspaces too small on account of the fineness of the grain.

(2) Parts having the interspaces between the large grains filled with too great a proportion of very fine grains.

(3) Parts having too large a part of the interspaces filled by the deposition of cement.

The general size of the grains is largely a feature originating with the deposition of the bed. The intermixture of very fine grains is only partly original, for at the time of compacting of the beds, some of the very fine surrounding material is forced into the peripheral parts of the sand-body. This peripheral zone is wider on the inflowing side of the current produced by the differential compacting of the beds.

Cementation is by far the greatest of these factors in making "close" a portion of a sand-body which is elsewhere a reservoir. Its importance is evident from the fact that only small "lenses" in the thick Hundred-foot sand of Pennsylvania, or in the Hartshorne sand of Oklahoma, which is 200 feet thick in places, are capable of a commercial yield. Yet if the amount of cement were as low throughout as in some parts, the reservoir would occupy a much larger part of the sandstone. The distribution of this cement is so irregular as to cause much of the uncertainty of prospecting, especially in "feeling out" to the edge of a pool. Any knowledge of the method of this cementation process becomes, then, of great importance. Yet, unfortunately, this is one of the least understood phenomena in geology.

The causes of cementation may be divided as follows:

(1) Crystallization from the solution of salts in an evaporating lake, lagoon, or sea, in which the sand was laid down. Thus we have gypsum in the Hartshorne sandstone at Red Oak, Oklahoma. Probably all the sea salts are to be found in some sands. Crystallization of this sort is more likely to be continuous laterally than vertically.

(2) Deposition from invading waters. Invading waters are of two kinds: those which are in general (*a*) descending, and (*b*) ascending. The descending water is limited to a relatively shallow zone determined by the outcrop at the lower levels of the horizons in question, or of other horizons in communication. Below this, the waters are in general ascending. Notwithstanding this, since the lines of least resistance are prevailingly along bedding planes, the motion is on the whole more horizontal than vertical.

The nature of the water differs in these cases. The sea water expressed from newly compacted beds has the least to contribute in the way of cementation. The descending waters, relatively rich in CO_2 from the air and the overlying soil, have a solvent action in the first rocks entered, but as soon as saturated become a source of cementation, since the contact with certain other materials may rob the water of some CO_2 and hence deposit $CaCO_3$.

The ascending waters contribute cement owing to the fact that the temperature and pressure are reduced as the higher levels are reached, and hence supersaturation produces deposition. But this deposition tends to close the paths followed because they are those of least resistance, so that new paths are then sought and in turn rendered less pervious. It is this fluctuation from path to path that causes cementation to be so irregular and makes so very difficult the laying down of rules by which its distribution may be generalized.

The upper surface has irregularities, produced by many causes that also determine the lower surface, but it is likely to be more even because: the upper surface of a sand-body has been "worked over and planed off" by the action of the waves. Because of this, some geologists[1] have objected to the view that the shape of sand spits, bars, etc., has an influence on the ultimate shape of the sand-body. There are at least two circumstances that may prevent this working over. Very violent storms at rare intervals establish sand bars of coarse sand at their breaker line some distance from shore. In the milder intervening weather the bar may not be destroyed, but become gradually covered up. Again, even more effective in making important sand-bodies, are the advancing hooks, as seen at Sandy Hook or Rockaway Beach or Fire Island. The sand here builds up a sand-body where the water is already too deep to permit this sand to be worked over. Lastly, we have the "point" where sand moves along the shore in two opposite directions, depositing sand at the point of opposition, as at Cape Canaveral. The sand, in this case, is piled up in dunes and is wind-sorted, as in "The Desert" in the Norfolk Quadrangle. The resulting sand-body must be affected by this local excess in spite of much reworking.

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[1] Shaw, E. W., Bull. A. I. M. E., 103 : 1451, July, 1915.

In contrast to the points of this type, we have the conditions of a cusped shore where points are rocky and project out far enough to arrest the lateral movement of most of the sand, and we have thick accumulations that can be covered only in the bays and especially on the windward sides of the points. Here then we have either a succession of sand-bodies, or one which is thicker at intervals.

Another cause for the preservation of sand bars and spits is sudden submergence. Although we grant that this is rare, it cannot be ignored, as the reality of sudden submergence is too well authenticated by the large number of knife-edge contacts at the top of sandstones, where overlain by thick shale or even by limestone.

An additional evidence of the fact that the reworking by waves does not convert all sand-bodies into plane-topped bodies is that soundings on a sandy bottom off shore beyond the action of waves, reveals bars, and banks as seen in the Norfolk Folio.[1]

It is probable that the exceptional sand-bodies seen in the Glenn and Cushing pools have been formed as hooks or points, or in bays as outlined above.

The shape of a sand-body as seen from above, and the attitude of the floor and roof differ markedly from the shape and attitude of a disc or a lens with circular, horizontal sections, and these differences result from the method of action of the formative agencies. The following generalizations regarding sand-bodies seem to be justified.

(*a*) Sand-bodies are frequently oblong.

(*b*) These long axes are prevailingly parallel at any one horizon in one region, and somewhat less so in one region in successive horizons, or in one horizon in neighboring regions.

(*c*) This prevailing axis direction approximates a direction parallel to the hypothetical shore line at that horizon.

(*d*) [2] To a much less degree the prevailing direction of the axes is parallel to the prevailing direction of the axes of deformation, since the shore line partly determines the axis of deformation; or they may both have a common cause.

(*e*) The under surface of the reservoir is more uneven than the upper surface.

[1] U. S. Geol. Survey, Folio No. 80, Norfolk, Va., Quadrangle.

[2] From the thesis of W. E. Bernard in the Library of the University of Pittsburg. "On the Relation of the Pools to Folds in Pennsylvania and West Virginia."

It must not be overlooked that the rules above apply to the whole sand-body, and that the reservoir itself occupies only a part of the sand-body. Concerning the shape of the reservoir a few generalizations are possible.

(1) The reservoir is a coarser part within the general sand-body. This part is influenced in some degree by the same agencies that determined the shape of the whole body.

(2) A reservoir is larger as a gas reservoir than as an oil reservoir, since a commercial quantity of gas can be produced from a less porous rock than a commercial quantity of oil at the same pressure.

(3) Reservoirs are much more restricted laterally than is commonly supposed. When they are extensive laterally, they frequently are thick enough to constitute a commercial pool only in one or more areas relatively small in comparison with the whole sand-body.

(4) The "tailing" of reservoirs is generally sufficiently gradual, so that drilling at the edges may be discontinued past a well where the sand was found much thinner, rather than be carried on until a dry hole is obtained.

(5) Since sand-bodies frequently become gradually less porous laterally from an increasing proportion of clay or other fine material, the edge of the reservoir may be "felt for" as in the case of tailing.

(6) There is an individuality to different sand horizons that makes it possible to "feel out" from productive wells in a way adapted to the particular sand, so that there will be fewer dry holes. The "Hundred-foot," Third, Bartlesville, Hartshorne and McEwan (Dewey shallow) sands are examples.

CHAPTER VIII

CLASSIFICATION OF THE ATTITUDE OF GEOLOGIC SURFACES

The familiar classification of folds has long been used by the geologist in working with oil and gas. Its inadequacy for his purposes is apparent when one considers that the determining factor in the gravitational separation of gas, oil and water is not the general plane of the bed, but the actual surface constituting the roof or floor of the reservoir. This may differ from the general plane of the bed not only on account of irregularity of deposition, but also on account of irregularity of cementation, since the reservoir frequently constitutes only a portion of the sandstone bed. A classification merely of folds does not suffice, because it is the upper or the lower surface which concerns us, and they are frequently not parallel.

A lenticular bed which lies in general horizontally, is not a fold at all, nor is one lying in a plane monocline. Yet the upper and lower surfaces of both of these have an attitude which is of great moment to the oil geologist, and must be considered along with the folded surfaces.

A classification of geological surfaces is therefore needed here. There are four prime divisions:

1. Acline — a surface with no inclination — a flat surface.
2. Homocline — a surface with inclination in one general direction.
3. Anticline — a surface with inclination out from a point or axis.
4. Syncline — a surface with inclination in toward a point or axis.

Acline

The acline is of small importance, because one finds so generally that there is at least a slight inclination to beds, either deformational or depositional. The terrace is an acline interrupting a homocline which continues with the same dip direction both above and below the acline.

The horizontal bed is rare because (*a*) beds are generally laid down on a shore which is an inclined surface, and (*b*) when the shore is raised at the time of emergence, some tilting usually results. Even if as a whole it is flat, the upper and lower surfaces are likely to have an inclination because of differences in deposition, compacting or cementation.

Homocline

Monocline is a much abused term. For many years, some have used it for "beds dipping in one direction," others for a "one-limbed flexure." The confusion is most unfortunate. Recently the situation has been made worse by writers, independently, advocating different solutions for the difficulty. The senior author[1] and Anderson and Pack[2] advocated monocline for "beds dipping in one direction," and monoclinal flexure for the "one-limbed flexure." R. A. Daly,[3] on the contrary, introduces the term homocline for the former and reserves monocline for the latter.

The problem now is to choose one term or the other, so as to get unity as soon as possible. Inasmuch as there was a favorable response to the introduction of the new term homocline at the 1915 meeting of the Geological Society of America, the senior author acquiesces in the new usage, believing that by so doing unity can be achieved more quickly than by any other course.

The homocline may be subdivided into three primary types:

1. The plane homocline — the whole surface having a roughly similar degree of dip.

2. The anti-homocline is a curved portion of a homocline which is convex, when seen from a point perpendicular to the general surface and above it. This is a very common structure. It is readily seen that it is analogous to an anticline and would become one if the surface in general were tilted to a more horizontal position. Similarly, an anticline tilted sufficiently becomes an anti-homocline. Orton, with this aspect in mind, called it an "arrested anticline."

3. The syn-homocline is a curved portion of a homocline which is concave when seen from a point perpendicular to the general surface and above it. It bears the same relation to a syncline that the anti-homocline does to the anticline.

4. The monocline. In addition to these fundamental units there is the very common combination of an acline passing into an anti-homocline, thence into a syn-homocline and ending in a homocline. This in less analytic language is "a single sharp bend connecting strata

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[1] Science, n. s., vol. 42, pp. 450–452.

[2] U. S. G. S. Bull. 603, p. 109.

[3] Canada, Department of Mines, Geological Survey, Memoir 68, p. 53.

which lie at different levels and substantially horizontal except along the line of flexure" or still more simply a "one-limbed flexure." The term monoclinal fold or flexure has been used frequently to describe it.

5. Half-fold. This same combination, except for the aclines terminating it at each end, is found in the half-fold, which is the whole surface from the axis of an erect anticline to the axis of an adjoining syncline; or if the anticline springs from a plane, to that plane.

Anticline

An anticline may for some purposes be analyzed into the two anti-homoclines of which it consists, these being separated by the crest. An anticline which arises from an acline on each side, rather than lying between two synclines as is the rule, consists of four units. Each side has an anti-homocline above passing into a syn-homocline below.

Anticlines are divisible into the following classes:

1. The *dome* is a surface dipping outwardly in all directions from a central point or line.

2. The *level axis anticline* is one where the surface is in general horizontal along the axis of the anticline. A very elongate dome may have a middle portion which is also a level axis anticline.

3. The *plunging anticline* is one having the axis itself inclined. An elongate dome is made up of two plunging anticlines, the plunges being in general in opposite directions. As stated above, a level axis anticline may intervene.

4. *Nose.* Two anticlines may cross each other. This generally produces a more or less marked dome at the intersection, which has radiating plunging axes. The anticlines are seldom of equal magnitude. If one of them is very much less than the other, it is seen merely as a wrinkle in the flank of the larger one. Since these are very common and confusion arises if they are called anticlines without qualification, the descriptive name of *nose* is used. A *nose* is a relatively minor plunging anticline on the flank of a much larger anticline or syncline or in a homocline. It causes the isobaths to show a mere wave in the down-dip direction.

Synclines

The syncline is classified in the same way as the anticline, giving us the opposite terms — *basin, level axis syncline, plunging syncline* and *chute.*

The term *chute,* while new in this connection, is needed. It may be defined as a "minor plunging syncline in the flank of a much larger anticline or syncline or in a homocline." It causes the isobaths to make a wave in the up-dip direction.

Saddles

A saddle is a down fold in the axis of an anticline, or an up fold in the axis of a syncline. This form partakes of the nature of both an anticline and a syncline, as is evident if a model in sheet lead is turned upside down. We find it is still a saddle, but at right angles to the original one.

For surfaces involved in recumbent, erect, carinate, isoclinal or fan folds, the present fold terms may be used without modification.

Just as we apply geanticline to a very large anticline embracing smaller folds, and anticlinorium to a mountain mass which is on the whole anticlinal, although embracing minor folds, so we have the corresponding names geosyncline and synclinorium. It now becomes necessary to add the corresponding words geohomocline and homoclinorium.

CHAPTER IX

THE EFFECT OF THE DIFFERENT ATTITUDES UPON ACCUMULATION

Effect upon gravitational separation. — The importance of the different attitudes of reservoirs to the oil and gas producer lies in the influence they have on the accumulation of oil and gas by virtue of the action of gravitational separation. Each type will, therefore, be considered in turn with reference to its effect upon accumulation.

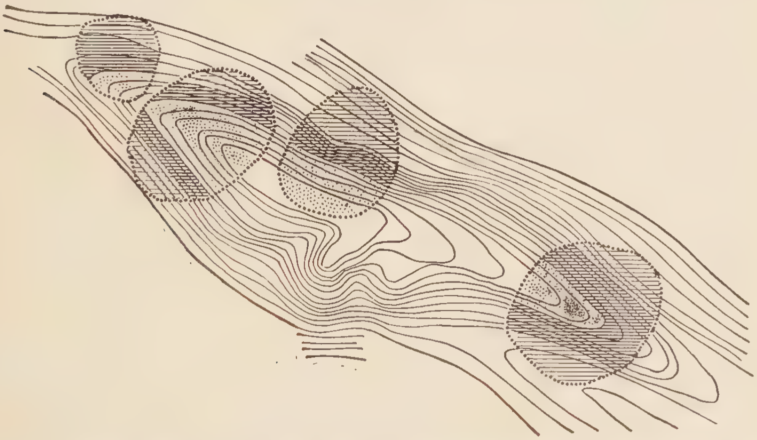

FIG. 33. Isobath map. Gravitational sorting as influenced by the size and position of the reservoir in relation to a dome. The isobaths (structure contour lines) show relative elevation above a reference plane.

Dome. — (*a*) Assume first that the reservoir extends past the dome in all directions. It is obvious that the dome accumulates gas more effectually than any other attitude. It is indeed ideal for oil also where gas is absent, and, given a favorable horizon and sufficient parallelism between the surface beds and the reservoir, one may prospect a dome for gas with greater confidence than any other attitude. If the actual dome in the reservoir "roof" is less than 10 feet in height, its value becomes dependent upon a high price for oil and gas, or upon a lower cost of production. In low domes the diameter of the base of the dome is likewise a factor of importance. A diameter base of less than half a mile is questionable.

Domes are generally found either along anticlines, or in a homocline of a larger order. Where the reservoir extends past the dome in all directions, the height and diameter of the effective portion of a dome is determined by its "spilling point."[1]

The spilling point is that point where gas passes out from the dome when it becomes over-filled, just as an inverted bowl of air held under water and then slightly tilted loses air bubbles at one point of the rim, and water enters the bowl to the level of this point.

But this plane, which we shall call the spilling plane, is not perfectly horizontal, especially in large domes. This is known from observation, and would also be expected since, with varying porosity of the sand, water naturally lies higher, where smaller pores increase the capillarity. The critical angle necessary to move water, in spite of friction, to a level would be lower as the distance from the spilling point increases. These deviations from horizontality are not so great as to cause the spilling plane to vary much from the horizontal, but are enough to make these variations too important to ignore.

Observe that any point, apparently on the dome from the curvature of the isobaths, but below this spilling plane, is, so far as oil and gas accumulation is concerned, substantially a part of the general homocline or general anticline upon which the dome is a bulge, rather than a part of the dome. This is because only that part above the spilling plane can hold gas, if there is a great deal of water. The spilling plane is of great importance in appraising leases on a dome, as those below the spilling plane do not share the same enhancement of value that a dome gives, but are to be compared with the plane dipping leases in that field.

The dome has far less promise for oil than for gas, owing to the fact that any increase in the amount of gas pushes the oil down its slopes and in so many cases below the spilling plane, where it is spilled out at the spilling point of the dome. This is an explanation of the fact that some gas pools are underlain by water with little or no oil. Of course, if the oil-water surface in the reservoir was below the spilling plane, the oil between it and the gas-oil surface would remain in place.

(*b*) We have so far considered that the reservoir is large enough to extend past the dome in all directions, but this is only one of several possible combinations, and was considered first because it is most easily understood. Inspection of Fig. 33 shows that other shapes of reservoirs do not reduce the chances of finding gas rather than water, but they do reduce the chance of a well at the center of the dome yielding gas.

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[1] Trumbull, L. W. The Effect of Structure upon Migration and Separation of Hydrocarbons. State of Wyoming, Geologist's Office, Scientific Series, Bull. 1.

While circular domes have been considered thus far for the sake of simplicity, they are really rare, the great majority being elongate. In the illustrations elongate domes have therefore been employed.

Level axis anticline. — The level axis anticline is as favorable as the dome for gas, provided its length is greater than that of the reservoir, and that the topography is not so incised as to expose the reservoir.

Plunging axis anticline. — The plunging axis anticline has less value than the level axis anticline. The greater the plunge of an anticline, the less its value as an aid to prospecting, until it is of scarcely more value than that of a plane-dipping homocline. This is because:

(1) With a steep plunge large reservoirs reach the surface and thus the contents suffer loss, only partially prevented by sealing in. There is also a loss of pressure.

(2) Where water occupies a portion of the reservoir, as is usually the case, then as the axis becomes more inclined, the lower fraction carrying water approaches closer and closer to the axis. With the axis still more inclined, water is found at the axis in the lower part of the reservoir. (Fig. 34.)

In anticlines which are relatively broad in proportion to their height, plunge is a greater detriment than in narrow ones, as there is greater chance of getting water on the axis.

Nose. — As the inclination becomes still greater, so that the plunging anticline is more properly designated as a "nose," we approach the condition of a homocline, and the advantages of the anticline over the homocline disappear.

Synclines. — Where the reservoir is much more extensive than a basin or level axis syncline, the syncline has a very high chance of containing water only, and is accordingly unpromising. The question of how much water the sand has is very important in such cases. There are a few guides for predetermining this:

(1) The amount of water in other reservoirs at the same horizon at similar depths, at not too great a distance.

(2) Where gas is relatively less common as compared with oil, water is more abundant, as in Illinois.

(3) In general, other things being equal, the shallower the sand the more water.

In practice, absence of water from reservoirs is seldom met. Some pools have been reputed to be free from water, when later a further extension down dip to one side has revealed its presence.

Just as anticlines with a greater and greater plunge become increasingly less promising, so the prospects on synclines in sand without water become less and less promising the greater the plunge.

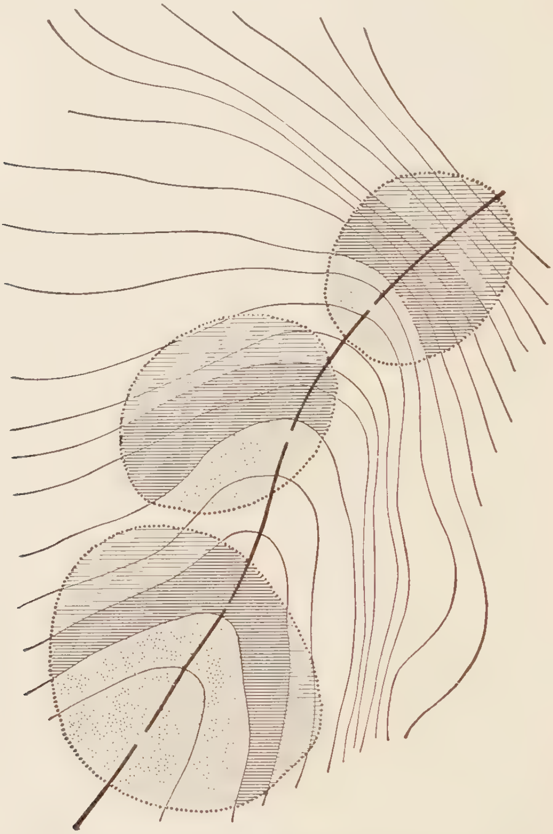

FIG. 34. The influence of the plunging anticline as affected by the size and position of the reservoir. Isobath map. Dotted area gas, close hatching oil, open hatching water.

Plane homoclines have stood in bad favor among some geologists. Thus it was omitted from Clapp's classification, and Hager states that "all oil is found on folds." Repeatedly lands have been condemned "from lack of favorable structure." To be sure, where a reservoir lies on a plane homocline, its presence cannot be detected at the surface, so that wildcatting gives fewer successes. This in nowise proves that such pools are not present. With a dip sufficient to produce gravitational separation, pools in a plane homocline differ in no way from the very numerous pools on the flanks of a broad anticline which are too small either to reach past the axis of the anticline or that of the adjoining syncline or anticline (Fig. 35). Mr. W. E. Bernard[1] finds that in West Virginia and Pennsylvania 78.5 and 74.7 per cent respectively of the

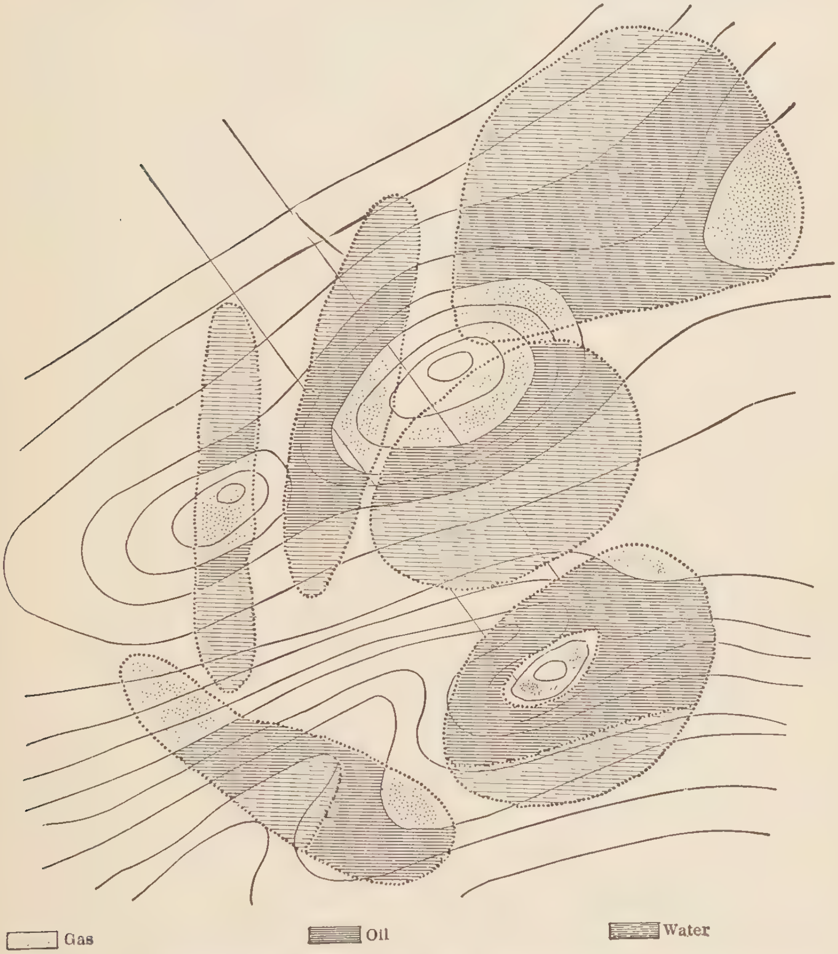

FIG. 35. Gravitational sorting as modified by the size and position of the reservoir. Isobath map.

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[1] Thesis in the Library of the University of Pittsburg. "Relation of Folds to the Oil Pools of Pennsylvania and West Virginia," pp. 27–28.

pools fail to cross the axes of the adjoining folds. That is, these pools lie wholly on a "half-fold," which is a homocline. In fact, these reservoirs had their oil and gas content in large part before the folding took place. If one of two similar reservoirs should come to lie in a plane homocline, and the other on a fold, what is there to destroy the oil and gas in either? Given the same dip, gravitational sorting works quite as successfully in one as in the other.

While plane homoclines are in such bad repute, changes of dip in homoclines are by many authors said to be very favorable. But the reasons given only apply when there is a change of dip from one inadequate to move the oil along the inclined plane to one that is adequate. But homoclines with remarkably slight dips have given us gravitational sorting. In fact, we have gravitational separation with dips so slight that no one has yet pointed out the lowest limit for effective sorting.

The terrace has been greatly overrated also. There is of course a certain geometrical advantage in drilling on a terrace, for a flatter reservoir offers a larger target. This advantage increases with the general dip of the homocline in which the terrace lies. It has little importance in the common low-dip fields. But this consideration is not the basis of its supposed great advantage. This is alleged to result from the fact that the oil, as it originally passed through the water, could be adequately moved until it reached the terrace, where, since the gradient was no longer adequate, the oil was simply left to accumulate. But on analysis we find that these pays are frequently 15 feet or more thick. Such an accumulation, however, itself gives a gradient adequate to move the oil a mile (assuming 15 feet a mile to be the minimum or critical gradient that is effective) even if the terrace is absolutely flat (Fig. 36). Many of the terraces cited are less than half a mile wide and many of them are not really aclines, but have a dip approaching the critical gradient. In fact, many terraces are postulated merely from a spreading out of isobaths without any actual evidence of the flatness of the bed.

It is very difficult to ascertain the critical gravitational gradient, because of two variables: (*a*) degree and types of porosity, and (*b*) direction and effectiveness of the current within the reservoir, which, with Washburne, we believe is generally flowing up dip. Even if we could know the critical gradient, it would avail us little, because convergence and depositional gradients make it impossible to know with sufficient accuracy the degree of the dip of either the roof or the floor of the reservoir.

Where the oil is found both above and below the terrace, it cannot be considered as the cause of the accumulation of the oil, as oil would in such a case occupy this part of the sand whether there was a terrace included or not. The terrace can be considered the effective agent in the accumulation only when water is found above the terrace, or in the case of dry sands, where the floor of the terrace is the accumulating factor, then, when gas is found below the terrace (Fig. 36).

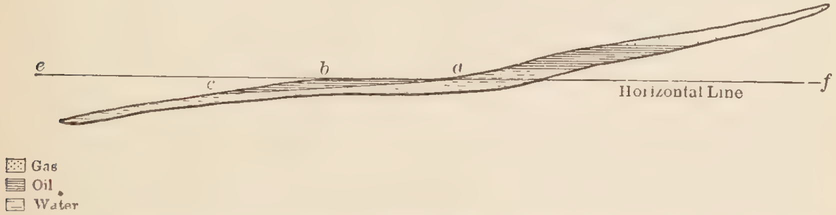

Fig. 36. Effect of a terrace below the water-level in accumulating oil. The slope of the line *ac*, the critical gradient, is exaggerated.

A terrace must not only be wide and flat to be effective, but it must be long and have a very low plunge — for it must not be forgotten that most subsidiary folds including terraces have some plunge. If the plunge is higher than the critical gradient, the terrace loses its oil up or down the plunge, according as water is or is not present.

The Glenn Pool has been cited as a case of terrace accumulation. This may have been based on new data concerning the top of the sand, and in that case may be correct for a small part of the pool. But if the conclusion was made on the assumption that the Glenn Pool reservoir roof parallels the contours given for the Fort Scott by Smith,[1] then the evidence is inadequate. Contour maps with 15-foot intervals or less do not show terraces explicitly. In this instance these structure-contour intervals showing a collective dip of 25 feet in a mile may or may not embrace a terrace. If we assume that there is a terrace, the reservoir extends past it to the north with a dip adequate for gravitational sorting. This extension would have permitted the oil to move on up the dip.

The terrace to be effective, then, must have almost no plunge, the terrace must be broad, and it must not be long enough to extend past the reservoir in each direction, so that the oil will not pass around the ends. These limitations reduce terraces to a low rank among favorable structures, together with the difficulty of locating them in the reservoirs, since convergence so readily extinguishes terraces found in surface formations, as one passes to successive formations below. Prospecting in certain of the Clinton sand districts in central Ohio has shown that terraces mapped in the surface formations and transferred to the Clinton sand by means of careful convergence sheets are very disappointing and not to be relied upon as oil accumulators. Nevertheless, they will in time receive a great deal of attention, since the more favorable known structures will have been developed, and the slightest advantage over plane homoclines will then be sought.

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[1] Smith, C. D., U. S. G. S. Bull. 541, Pl. 3.

Homoclines. — There remain for discussion the homoclinal reservoirs. These are very abundant, since so many pools we know are bounded by tight sand or shale, rather than by water sand. They hold a very large share of the world's oil, but unluckily by giving no local sign at the surface, the chances of successfully locating them are greatly reduced. Gravitational separation works in these cases more simply, yet a few circumstances call for especial attention. There is a widespread belief among oil men that gas sands, oil sands and water sands exist as separate reservoirs. While this opinion is based upon observations, and there are pools which contain only one or two of these materials, it is in general incorrect. The error is based upon observations which are improperly interpreted. Fig. 26 indicates why the drill so frequently passes through a "break" of shale or a "shell" of limy sand from gas into oil, or oil into water.

In cases where a reservoir lies in beds which are flat or substantially flat, there are nevertheless inclinations of the roof and floor of the reservoir (Fig. 37). While this is well known to producers, its effect upon gravitational separation has not been adequately realized, for the degree of these inclinations has been erroneously supposed to be insignificant compared with the dips that are found. For this reason an oil field need not be condemned if the strata at the surface are substantially flat, as at Electra, Texas.

If the view expressed in a previous chapter, that there is a movement of the oil, gas and water in the strata, is true, certain paths must be favored because offering least resistance. Selective segregation is therefore most active in and near these paths, and the assistance that motion gives to gravitational separation more operative there. M. J. Munn,[1] under the title "Hydraulic Theory," has developed the importance of this movement. While giving adherence to this view, we dissent from Mr. Munn's conclusions that "movement through the beds would not be uniform, which would finally result in zones of conflicting currents of water, between which the bodies of oil and gas would be trapped and held." This view he illustrates by supposing an invasion of a body of water into strata represented apparently as free from water. But these strata were all laid down, as he elsewhere states, with an initial charge of water, which is moreover here under high pressure.

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[1] Econ. Geol., IV : 509–529.

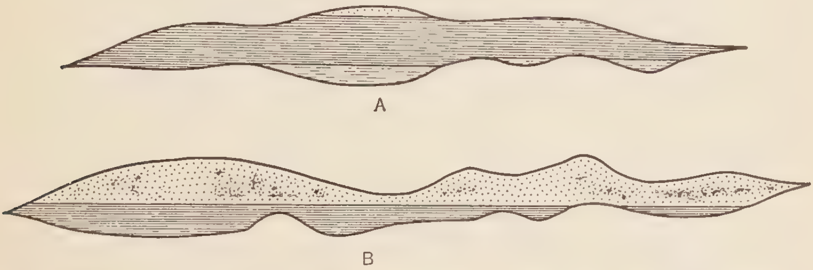

Fig. 37. Vertical section. The relation of shape of reservoir to the accumulation of its several contents. Dotted space = gas; lined space = oil; broken lines = water.

The hydraulic factor as used by Munn postulates descending water. But there can be little descending water except in parts of reservoirs higher than the lowest outcrop, on account of (1) the initial charge, and (2) the large amount of dynamo-chemical gas formed in the rocks under cover, whch makes a counter-current upward.

While these favored paths are in large part determined by the stratigraphy, yet the attitude is also a factor (Fig. 38). Along these paths more oil and gas is accumulated. But these paths change from time to time from one cause or another. They may be blocked by increasing cementation, or by the change in attitude of the beds, or the lowering of the surface by erosion may open up new passages by cutting into reservoirs. It would be useful for us to know such paths, but the difficulties are great. However, there are two places which may be regarded as likely paths. One is in the plunging anticline, which makes it less inferior as a prospect to the level axis anticline than it would otherwise be. Another path is along lines of maximum bending, as along the crests of anticlines or along other flexures, where the beds are of such nature that fissuring may take place. In such instances we have an additional value given to the fold in prospecting.

In Fig. 38 some paths of less resistance are shown for southwestern Pennsylvania, leading from a number of arbitrarily selected points. In this an horizon is assumed as having equal resistance on all sides yet

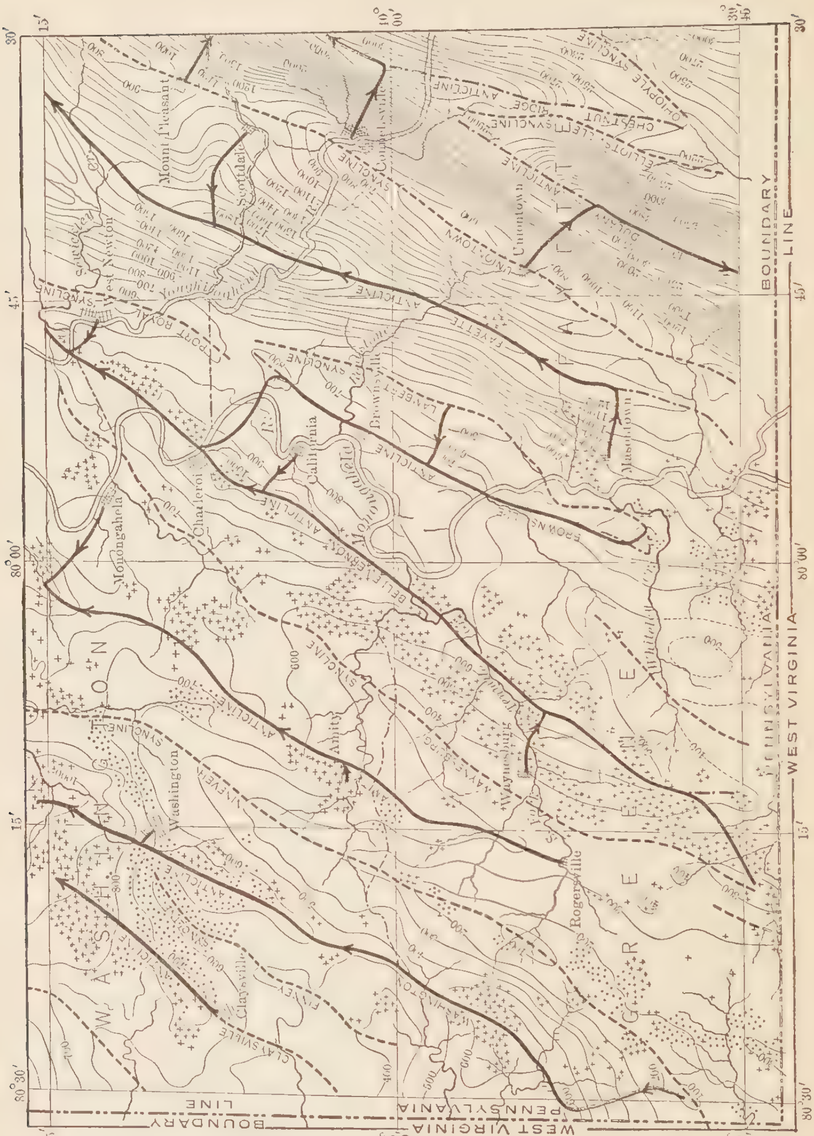

FIG. 38. Heavy lines are paths in a sheet sand that gas would take if unobstructed and if there was enough gas to fill the domes. Several arbitrary starting points were chosen. (Drawn on map from U. S. G. S. Bull. 456.)

having a more resistant roof and floor. Such a simple case is of course hardly ever found.

The fact that deep productive sands are so frequently found below shallow productive sands may be attributable, in some few cases, partly to this cause. It lends additional sanction to the practice of deepening wells in old fields before entirely abandoning them, unless the stratigraphic conditions are quite unfavorable.

In consideration of the action of gravitational separation, not enough attention has been given to the fact that folding has taken place frequently after the formation has been consolidated, and that the oil and gas had been in large degree already accumulated in the reservoirs, and had been already sorted by gravitational separation. In this case in a fold confined to the upper part of the reservoir, where gas only had accumulated, gas would be found at the bottom of the synclines that were later formed.

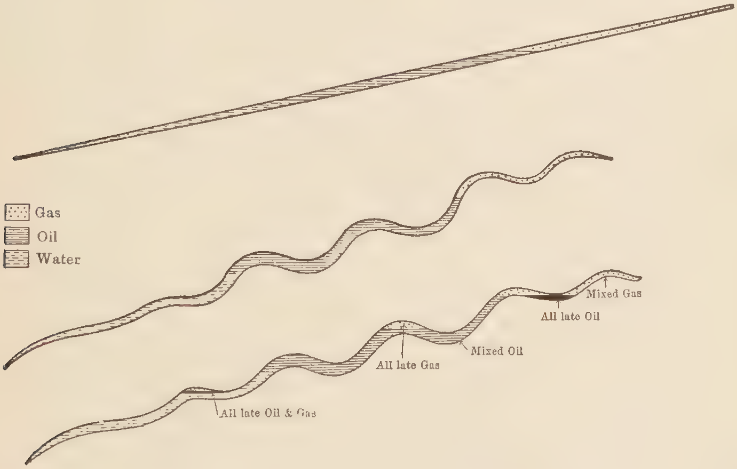

FIG. 39. Showing the effect of folding before and after gravitational sorting.

The foregoing applies to the oil and gas which was in the reservoir at the time of folding — the pre-deformational oil and gas. But there is reason to believe that a considerable amount of gas and a small amount of oil enters during the folding and subsequently. Some of this deformational and post-deformational oil and gas may be accumulated in these upper folds described above (Fig. 39).

Since the deformational and post-deformational oil and gas are of a different grade, as they were formed and had migrated under different conditions, we can in this way explain some of the contrasting qualities in the same horizon at no great distances, such as are occasionally found below the Bartlesville sand in the Osage Nation in Oklahoma.

The depth of any horizon below the surface fluctuates, depending upon whether deposition or denudation is in progress at the surface; and these processes have alternated several times in the history of some reservoirs. When the reservoir is deepest, the pressure being then greater, the gas content occupies a smaller volume, not only as a result of its greater compressibility but also because a larger percentage is dissolved in the oil and to a slight extent in the water. But if the surrounding beds are being compressed for the first time, new dynamochemical gas is formed as previously explained, so there may be a net increase of the gas volume. On the other hand as the depth is reduced, and hence the pressure, the gas volume enlarges.

Now if the folding takes place while the depth is relatively great, then anticlines, formed in the lower part of the reservoir where there is no gas, receive gas yielded from solution since as erosion reduces the depth of the reservoir, this gas is liberated into these lower anticlines. The composition of this liberated gas changes as the pressure decreases, since the solubility of the different gases differs, and also because some of the gases under the higher pressure are liquids. We have thus a further cause of variation in the quality of gas in different pools, depending upon the percentage of this dissolved and subsequently liberated gas that they contain.

CHAPTER X

LOCATING OIL AND GAS WELLS

Locating oil and gas wells is a fundamentally different process where the location is a prospect hole, or "wildcat," and where it is a well "feeling out" from known production. It is commonly believed that the geologist's services are limited to the first class and that the second operation is too simple to require his knowledge. This is erroneous, as will be shown.

Locating a prospect. — The location of isolated wells involves a consideration of the following factors:

(1) Choice of horizon.
(2) Choice of the nature of the beds.
(3) Choice of the attitude of the beds.
(4) Convergence of the beds.
(5) Gas, oil, and asphalt at the surface.

All too many oil producers have settled down into a fatalistic habit of thinking that the success of tests is so uncertain that no care or skill is required in their location. This is a very costly blunder. While all experienced persons know full well the uncertainties of drilling, the demonstrable success of improved methods in locating wells is so manifest that a neglect of geological considerations bespeaks incompetence.

In locating test wells the first requisite is to determine that the geological horizon is a favorable one. From our discussion of the stratigraphic distribution of oil and gas (p. 26), it is clear that pre-Cambrian beds are to be avoided, and that Cambrian beds are not considered favorable for oil, although they cannot be said to be hopeless. In the Upper Devonian vascular plants having tissues much more resistant to rapid decomposition, first become abundant. It is probably for this reason that oil and gas is progressively less abundant below this horizon. The lower limits of commercial production at present are the Trenton for oil and the Potsdam for gas. Prospecting in the pre-Cambrian is not to be encouraged, though occasionally, when the pre-Cambrian is in some particular relation with other formations, it has derived oil or gas from them. It must be said that in America, however, the producer finds much more encouragement in the formations from Ordovician to Upper Pennsylvanian, and again from Upper Cretaceous through the Tertiary. (Fig. 18.)

The poor showing of the Permian (except the very oldest), the Triassic and Jurassic, may offer some discouragement in the United States, but need not be heeded elsewhere.

The nature of the beds is of vastly more importance than their age. Ideal conditions are furnished by extensive dolomitization of limestone or beds of porous sandstone, 5 to 100 feet in thickness, lying within shales twice or more as thick again. The shales should be gray, black, brown or greenish in color. White, yellow, red, and purple shales are unpromising. Outcrops bearing asphalt or ozokerite (mineral wax) are indicative of the presence of petroliferous beds, but by no means are infallibly safe indications of commercial production. Nor on the other hand, does the lack of such evidence condemn a region. Drilling upon dips of less than 5 per cent are to be preferred, but are not necessary (Fig. 40).

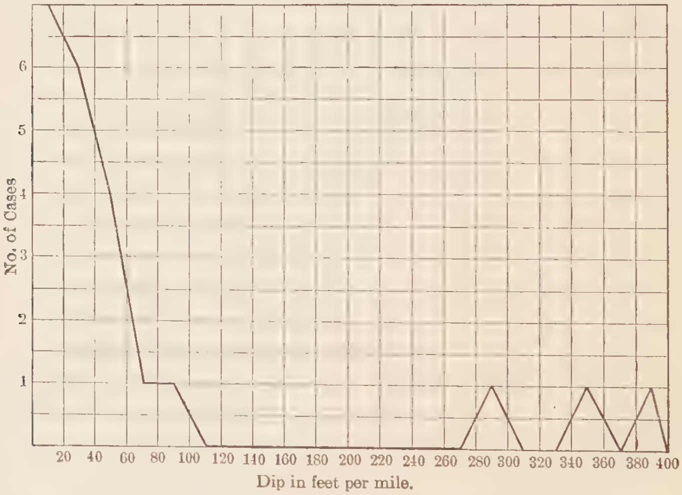

Fig. 40. Graph of frequency of various dips compiled from all the pools in a district of southeastern Ohio and northwestern Virginia.

The expected sandstones should be at a suitable depth at the selected point. An adequate cover without too much faulting is to be desired. This requires greater thickness in the case of gas, where high pressures are desirable, than with oil. Yet it is rarely wise to go to the very considerable expense of deep drilling when the expected sand lies below 3500 feet. However, other exceptionably favorable circumstances might make it worth while, such as very promising geological conditions, high price of oil, or very large amounts of land owned or leased by the company.

Tests in new territory are best located at the highest points of well-marked domes. In the event of the dome being unsymmetrical in its dips, the well should be drilled at a point,[1] best determined graphically, toward the lesser dips from the center, since the dome in the sand does not lie directly under the dome on the surface. And next, where domes are not available, anticlines with level axes are to be preferred. Anticlines that plunge become proportionately less valuable.

Gas, oil, or asphalt at the surface indicate either that (*a*) the beds or rocks in which such seepages occur are oil or gas bearing, or (*b*) that there is a migration of the oil or gas from deeper formations that are or were oil or gas bearing. If a gas is high in hydrocarbons it is probably of organic origin. On the other hand, if it is high in nitrogen, carbon dioxide, or sulphur dioxide, it may be of volcanic origin.

If seepages occur from an extensive outcrop, particularly if the asphalt or bitumen is entirely solid, they cannot be considered sufficient warrant in themselves for drilling wells to such an outcropping bed near the seepages. They are, however, favorable indications as to the oil-bearing character of such beds, which should be prospected at other localities where favorable structures are known.

If such seepages are still active, and the beds dip steeply, it may be worth while to drill just far enough back from the outcrop to get pressure and cover for any oil accumulation, in the outcropping bed, which is retained by partial sealing in. If seepages occur in igneous rocks, near a sedimentary contact, the sedimentary beds should be prospected rather than the formations from which the oil actually exudes.

Following up a discovery.—When either oil or gas has been discovered in a well, skill is necessary to locate adjacent wells in the most favorable direction, and also to choose and secure leases wisely, in order that there may be a minimum of dry holes and worthless leases. The producer may proceed according to several methods.

(1) The first of these is the method of *strike*. By this method new locations are made away from the discovery well in the two directions of the strike, that is, in such a direction that the sand is found at the corresponding level. This can be ascertained by learning the lay of the beds at the surface. From this data a map of some upper formation

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[1] Holland, Sir T. H., Some Geometrical Features of the Anticline: Jour. Inst Petrol. Technologists, Vol. I, pp. 13–27.

is prepared and when enough holes have been drilled the convergence, or lack of parallelness between this upper bed and this sand can be mapped and allowed for. Then a map of the particular oil sand can be made as is later explained in detail.

(2) *Method of dip.* — In the event that a well has oil only in the lower part of the sand and gas in the top, when oil is sought for, the next well should be drilled down the dip, in order to reach the sand where the oil pay is relatively thicker. Conversely, where the oil is within a few feet of the top of the sand and is underlain by water, the next well should be up the dip.

(3) *Method of streak.* — Oil reservoirs have neither uniform thickness nor, usually, great extent from side to side. More frequently than not, the oil sand extends farther in one direction than at right angles, making what is known to the producer as a streak. In any one particular horizon, these streaks, though variable, generally have a prevailing direction. A comparison of near-by streaks in the same sand, or if these are lacking, of other sands in the same field, offers some guidance. The producer should be alert to detect the thinning or reduced porosity in the several directions, in order that the streak direction may be inferred as early as possible. The method of streak is also valuable in connecting up two groups of wells, each centered around a successful test in one streak. This possibility should always be kept in mind when the two groups are not separated by a distance exceeding the reasonable and common area of the reservoirs in that sand. And again the possibility should be kept in mind when the producing sand is at the same depth below a reference horizon in each case and when the gas, oil, or water of the two groups of wells are of similar quality. The prevailing direction of the long axis of these sand-bodies (or of the pool axis, if the data is not adequate for recognizing the former) is most easily expressed by means of polar coördinate paper as in Fig. 41. The relative importance of streak and strike in determining the long axis of any field is well represented, after the strike has been determined, by plotting the angle, which the long axis of the pool makes with the strike, as in Fig. 42.

(4) *Method of inferred shore line.* — In fields where development has not gone far enough to determine the prevailing direction of the streak directly, an inference of some value may be based upon the probable shore line at the time of deposition. This requires the broad knowledge and experience of a geologist, who, in brief, would base his conclusions on the following principles. In general, the shore line lies at

right angles to the direction of deepest water on the one hand, and of the dry land on the other. The direction of deepest water is indicated by increased thickness and purity of the limestones. The direction toward the continent is shown by increased coarseness of the terrigenous material and the greater time interval represented by the unconformities. The present distribution of outcrops of different ages can also be used, but with great care, since subsequent movement and erosion of the beds introduce many complications.

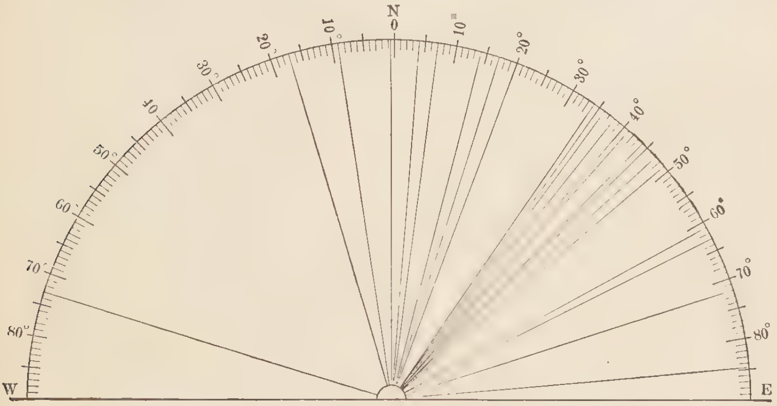

Fig. 41. The direction of the long axis in the same pools, as in Fig. 40, showing the origin of the common belief that N. 45° E. is the prevailing direction in this region, and at the same time showing how variable the prevailing direction of the long axis is.

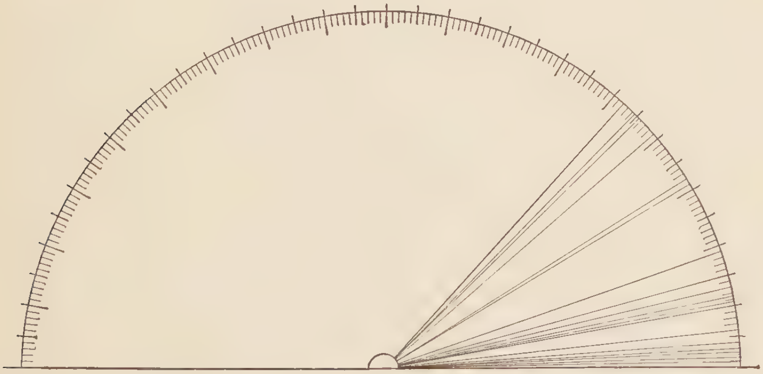

Fig. 42. The deviation of the long axis from the strike in the same pools as in Fig. 40.

(5) *Method of proximity.* — The rule of drilling next to good wells may seem too axiomatic to be dignified as a method. Yet one of the most important decisions a producer must make is that of leasing nearer to or farther from a discovery well of known production at correspondingly graded prices. It is therefore imperative that he estimate the relative values of different degrees of proximity. To do this we take statistics of the dimensions of the known pools in that sand or in

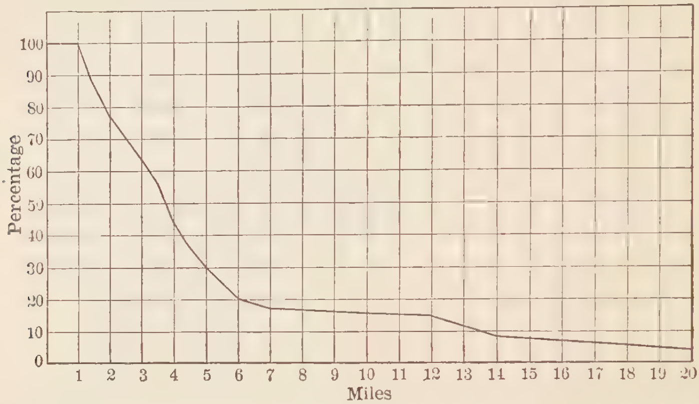

FIG. 43. The percentage of the number of the same pools as long as or longer than the distances indicated.

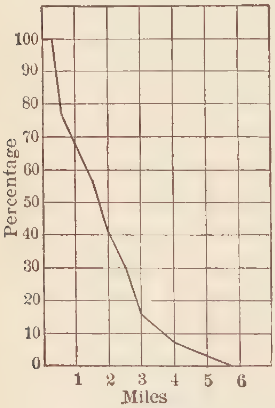

FIG. 44. The percentage of the number of the same pools as broad as or broader than the distance indicated.

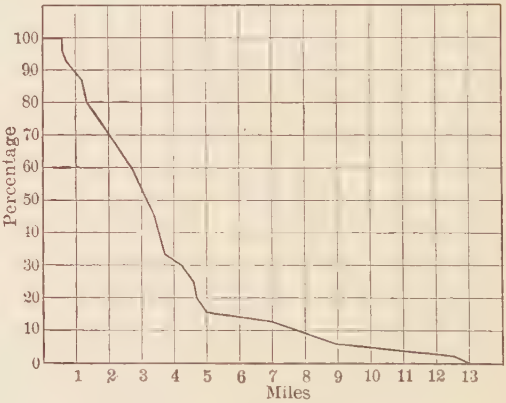

FIG. 45. The percentage of the number of the same pools having an average diameter as great as or greater than the distances indicated.

sands that seem most comparable. These should be plotted in a cumulative curve of frequency, separately as to the long axis (Fig. 43), short axis (Fig. 44), and for both axes of the pools (Fig. 45). From such curves the relative chance of a pool being of any particular size may be calculated without too excessive an average error. From this, and upon an estimate of the value of acreage indicated by the discovery well, after making some allowance for the insurance of risk, one can decide upon a proper price for leases at given distances from the discovery well.

(6) *Method of pressure decline.* — Unusual persistence of pressure after prolonged flow is of the highest value as indicating undrilled, contiguous, productive areas.

(7) *Method of chemical analysis.* — When the gas from a gas pool is dry and light, we may infer that the reservoir contains no oil, and save ourselves the expense of drilling further down the dip, so far as that sand is concerned. But allowance must be made for the fact that with greater pressure, the gas must necessarily be lighter and drier, even though the oil is in the same reservoir. If, on the contrary, the gas is heavy and oily in odor, we have strong indications, unless the sand is of extremely fine porosity, that prospecting down the dip offers encouragement. But when the gas is intermediate in quality, rather than markedly light or heavy, then a chemical analysis or compression test should be made. The results would guide the producer's further operations and also determine whether a gasoline extraction plant is advisable.

The value of thus ascertaining the nature of the gas, for the purpose of getting information as to the probability of oil being found in the same sand, is now becoming recognized among operators. This is determined generally by the odor, or the weight judged by the behavior of the gas as it leaves the hole, or by its condensation "in drips." Another rough method that might well be tried is to pass a stream of bubbles of the gas through ice water, or even onto a cake of ice, to observe if an iridescent film of oil is formed.

The Bureau of Mines has shown us the value of the determination of the specific gravity and the claroline absorption index, and it is to be hoped that it will supply us with a larger series, giving in each case tests of casing-head gas by these two methods and by a standard compressor-condensation plant such as could be mounted upon an automobile chassis and operated under standard conditions. Not until then can we know just how to interpret specific gravity and claroline absorption tests. We should also have evaluation of the rough tests mentioned above by comparison with specific gravity, claroline absorption, and the standard portable plant.

Another factor, which must be standardized before the analyses of gas can be readily used, is the changing content of the condensable constituents (*a*) as the pressure decreases, and (*b*) as the gas is distant from the oil in the same reservoir.

The analysis of oil may be of use in making locations in the following circumstances: (1) To find if two pools some distance apart may be in the same sand, as in that event there would be a stronger chance of production in that sand in the intermediate territory. (2) To determine whether a given sand is the same as an outcropping sand showing asphalt or ozokerite. (3) A very heavy oil at a considerable depth causes us to suspect a near-by fault or outcrop, whereas an oil of extraordinary lightness has probably moved a long distance and has been subject to considerable fractional filtration. This is, therefore, less likely to be a successful commercial proposition, as in the recent strike at Calgary, Alberta. On the other hand, such light finds are an indication of the general petroliferous character of the strata.

In the case of salt water, an analysis may also be of value. The nature of the salts it contains will assist in the correlation or non-correlation of the two sands in question. It will also help determine whether the water pumped with the oil comes from the producing or some upper sand. But most important of all is the fact that methane and the next four members of the paraffin series are soluble in water to an extent of about 3 per cent, which varies of course with temperature and pressure. We may then analyze the water from a particular sand and can deduce from the content of methane and ethane the presence or absence of natural gas in the same sand farther up the dip. And if the analysis shows the higher paraffins, such as propane and butane, we should expect oil also in the same reservoir farther up the dip. If a test hole on the side of an untested anticline encounters water, we may determine by this method of analysis whether another test up the dip will be worth while.

Producers might wisely urge the Bureau of Mines to make a large number of comparative analyses to be used as standards of comparison, and further, to compare the various, possible analytic methods with respect to their economy and efficiency for this class of work. In the meantime, however, we may employ current methods. The Pittsburgh Testing Laboratory is prepared to test for dissolved gases in salt water. The Bessemer Gas Engine Co. is constantly making gas analyses, for the purpose of ascertaining whether the quality of the gas warrants the installation of a gasoline extraction plant. The method of sampling is of supreme importance in either case and should be done according to explicit directions.

(8) *Geothermic method.* — Hoefer believes, and presents some evidence to substantiate his theory, that the increase of heat with depth is greater over oil deposits. The Carnegie Geophysical Laboratory is investigating along this line. But it must be said that the outlook for a successful use of this method is not very promising. It is difficult to see any connection between the isogeotherms and oil. It would appear theoretically more reasonable to look for the association of gas with isogeotherms. But nothing can be done in a practical way until the whole subject has been very much more thoroughly reported upon.

Location of tests for deeper drilling. — An oil pool is sometimes developed with shallow wells in an upper formation. It may be known, or suspected later, that this shallow pay is underlain by one or more favorable horizons at which deeper drilling may develop oil or gas production. Or this deeper drilling may not have been warranted in the early history of the pool, owing to the low price of oil.

When the oil or gas reservoir straddles an anticline or dome, it is well known that if the oil is accompanied by gas the latter will be found to occupy the highest portion of the reservoir at the top of the fold. But in the shallower formations there is usually a smaller proportion of gas to oil. Hence the space occupied by the gas is relatively smaller in the upper sands, and in these sands the oil lies closer to the crest of the fold than in the lower formations.

In a field such as that at Newkirk, Oklahoma, the limits of the pool in the shallow sand were defined early, and leases were abandoned on the edges where dry holes were encountered. It is quite probable that oil production will be developed in some of the lower sands which are known to underlie the Newkirk field, on previously condemned edge territory. It is also probable that gas will be obtained by drilling to the deeper sands on the crest of the anticline. (Fig. 47.)

The distance of wells apart. — In spacing wells, the fundamental idea is to obtain the largest feasible amount of drainage of oil from a maximum amount of territory with the minimum number of wells. To do this the operator must take into consideration a number of factors, some of which conflict with others:

(*a*) Porosity and hardness of the sand.
(*b*) Character of the oil — viscosity, gravity and whether or not it is asphaltic.
(*c*) Dip of the formations.

(*d*) Property lines and off-setting wells; whether drilling agreements can be made with neighbors or whether aggressive operations must be resorted to.

(*e*) Amount and pressure of gas in the oil sand.

(*f*) Water conditions in the oil sand.

(*g*) Financial considerations. That is to say, how many wells must be drilled annually to keep up the production; and also whether it is the policy of the company to drill rapidly and tank the oil, exhausting the property early, or whether to drill more slowly and drain the property with a fewer number of wells in a longer time. If the question of a rapidly declining gas pressure is involved, the first policy is preferable, even though the oil is produced during a period of low prices.

In fields such as certain of the Russian and California pools, where the oil sand is thick, unconsolidated and very porous, especially where large quantities of loose sand are expelled with the oil, wells are spaced very close together primarily because the yield is so great that economy of spacing is neglected. In such sands one well will often drain a very large area, and close spacing is unnecessary. The drainage channels set up by wells in a soft sand field are so erratic in their direction and extent, that mutual agreements between operators as to spacing and off-setting wells may not always be justified. A lease of very irregular shape must have more wells per unit of area than a large square block, and is therefore less valuable than the latter.

In those fields producing heavy viscous oil with relatively little gas, it is obvious that wells should be spaced very close to effect a maximum extraction.

In an oil pool situated in a region where the formations have a pronounced dip usually the best practice is to space wells closer across the dip than down the dip. Figs. 46, 47 and 49, from Slichter's discussion[1] of the mutual interference of artesian wells, show a number of ways in which oil and water are diverted by wells, either flowing or pumping. Fig. 46 shows the lines of flow into a well in a region where the fluid has a constant motion in a general direction. If a second well were drilled in the neutral zone *O*, its production would be considerably smaller than that of well 1. This figure, in connection with Fig. 47, will indicate the advisability of spacing wells closer across the line of dip or flow than down the dip. In the West Virginia fields, and in a few Oklahoma fields, where operators control large blocks of territory, wells are being spaced one well to 10 acres.

In the Cushing pool in Oklahoma, wells were spaced on an average of one well to 8 acres. There were apparently drilling agreements

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[1] Slichter, C. S., U. S. 19th Annual Report, Pt. 2, p. 377.

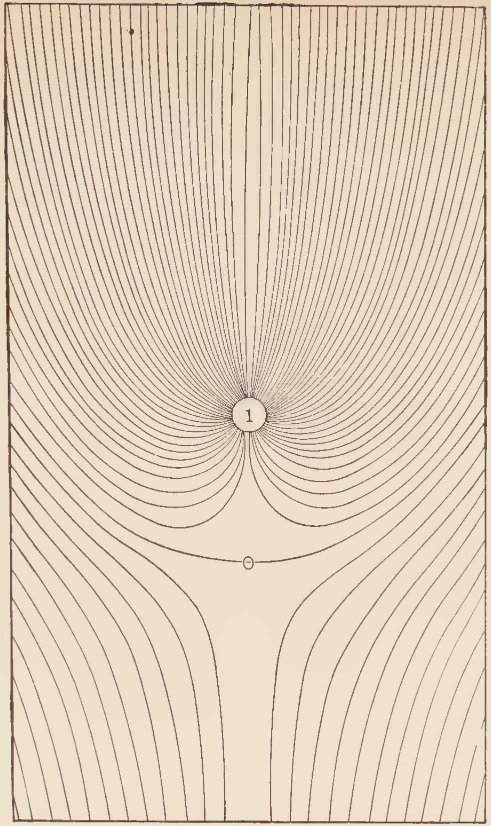

FIG. 46. Lines of flow into a well in a region where the water or oil has a constant motion in a general direction.

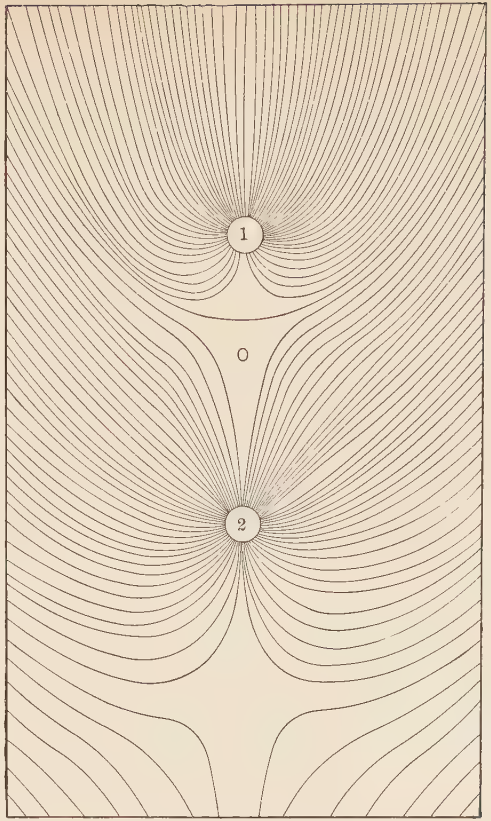

FIG. 47. Lines of flow into two interfering wells.

among a number of the operators, which were made possible by the comparatively large size of the leases and the similarity of interest along certain lines among the larger operators. The Glenn pool was over-drilled, partly because of a lack of knowledge, partly because of the smaller size and irregularity of the leases and the larger number of small operators. This brings up the question of the advisability of drilling all inside locations as soon as possible. The operator should consider that in hard rock and low dip fields the gas pressure is by far the most important factor in bringing the oil into the well. When this pressure has been lowered by surrounding wells, later wells drilled upon inside locations will not be able to recover nearly so large a percentage of the oil content of the sand as would have been possible had they been drilled earlier when the pressure was high. Thus inside locations are likely to be small producers, unless they are rushed in as soon as possible after boundaries have been protected. They are usually inadvisable in tracts of 80 acres or less.

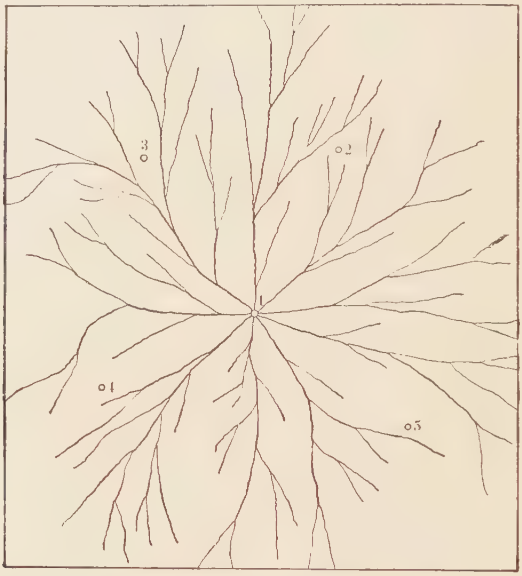

Fig. 48. Drainage lines of one well. After Hager.

Slichter[1] demonstrates that in water wells in homogeneous formations, the total flow of two wells 200 feet apart is about 169 per cent of the flow of a single well. If a third well be placed midway between the two, so as to make a row of three wells 100 feet apart, the total combined flow from the three wells is about 207 per cent of the flow of a single well. On the basis of relative viscosities of light crude oils and water, the same figure is said to apply approximately to oil wells 400 feet apart. Since this calculation disregards differences in the porosity of the sand, varying gas pressures, etc., the determination has no practical value. In a normally tight sand, wells must be drilled closer together in order to drain the territory at the same rate. In such a tight sand neighboring wells do not affect each other to the same degree as in a very porous stratum; that is, pronounced drainage channels toward the wells first drilled are not formed.

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[1] Slichter, C. S., U. S. G. S., 11th Annual Report, p. 377.

Figure 48 indicates how the first well (1 in the figure) drilled in loose unconsolidated formations, such as the Tertiary and Cretaceous sands of California and Louisiana, will set up drainage lines[1] in all directions, so that later wells (2, 3, 4 and 5 in the figure) will produce less, although there are still large quantities of oil in the field. Well 1, however, continues to produce prolifically. Fig. 49 shows the lines of flow for two interfering wells in the case where one well has double the capacity of the other, the sand presumably being more porous.

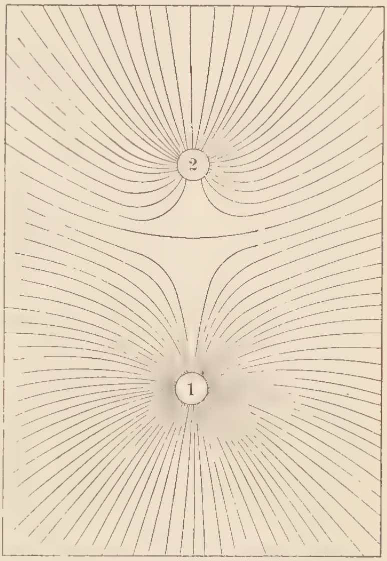

Fig. 49. Lines of flow into two interfering wells, one of which has doubled the capacity of the other.

Town-lot development and the conditions brought about by many operators with small leases fighting for production result in extravagant and wasteful methods of production Likewise, in the case of the minor leases — the so-called "short-term" leases — operators have been led to drill uneconomically in order to extract the maximum amount of oil before the leases expired. Such development means uneconomical production by drilling more wells than are necessary, pumping too fast, wasting gas pressure (and the gas itself), and flooding wells.

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[1] Hager, Dorsey, Geological Factors in Oil Production, Min. and Sci. Press, vol. 103, Dec. 9, 1911, p. 740.

In the Oklahoma field half a million dollars has been spent on unnecessary wells in two square miles. Nearly any field shows most extraordinary waste from too close spacing. A marked contrast, as regards closeness of wells, may be observed in almost any field where one company owns a very large tract and a group of small, competing leasers hold adjoining properties. No general rule can be made as to the proper distance between oil and gas wells. For each sand, the producers must watch closely the results of wells drilled later among the older wells. Since it is the common practice to lease in blocks or multiples of blocks of ten acres which equal 660 feet square, it is wise to put oil wells at this distance of 660 feet from each other, if this is approximately the distance that would have been selected for other reasons. There is a strong tendency to observe this distance among Mid-Continent and Illinois producers at the present time. In California, they still drill closer than that ordinarily, because of the large size of the wells. And in the Appalachian field the leases are so irregular in shape that there is less incentive to conform to this particular distance.

Gas wells may be spaced at much greater distance, 1320 feet being sufficiently close.

When wells for either oil or gas are drilled on a very large tract of land so that the offsetting of neighbors' wells is not a consideration, there is a more economical arrangement than the old one of locating the wells in straight lines crossing each other at right angles. By a staggered, or quincunx arrangement, all of the given area may be brought within closer range of some well center. Unfortunately the staggered arrangement is seldom feasible on smaller leases held by competing producers for on these small leases there is generally a well located in each corner. Between these corner wells, other wells are distributed at a distance from the property line equal to the distance at which the neighbor's wells stand back from the line.

However, it is by no means advisable to put in as many wells between the corners as the neighbor does. Very frequently a conference between two neighboring producers may lead to an agreement not to drill an additional well between the two that may be already producing along a 1320-foot side. Whereas, without such an agreement, one of the producers might drill in between, which would nearly always lead his neighbor to meet him with an offset, though it would be to the ultimate interest of both not to drill these accessory wells. The same situation arise inevitably on all sides of a lease. A producer should always seek to enter into an agreement with each one of his neighbors, to the end that their wells may be as nearly 330 feet back from the line and as nearly 660 feet apart along their lines as each will consent to. This is, of course, if 660 feet has been decided upon as the best distance for that particular sand and depth.

The accompanying table gives the territory lost if one does not offset in the most familiar situations that arise:

Offsetting

	200 ft. from line.	150 ft. from line.
	Acres.	Acres.
Along the long side of an eighty;		
Case 1, 5 wells meeting 8 on the side of 4 tens loses	1.65	1.[illegible]
Case 2, 5 wells meeting 6 on the side of 2 forties loses......	0.55	0.90
Case 3, 4 wells meeting 5 on the side of an eighty loses	1.01	1.[illegible]
Along the side of a forty;		
Case 4, 3 wells meeting 4 on the side of a forty loses.......	0.24	0.42
Case 5, 3 wells meeting 4 on the side of 2 tens loses........	0.13	0.41
Case 6, 2 wells meeting 3 on the side of a forty loses.......	1.39	2.65

The method of ascertaining the lost area is to draw lines on the map midway between each line well and its two opposing line wells, if one is not exactly opposite. This is done by drawing circles with each well in question as a center and joining the points of intersection with a line. These lines make triangles with the lease boundary showing areas lost or gained.

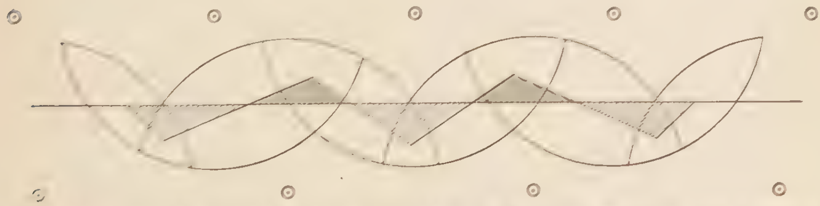

Fig. 50.—Graphic method of calculating loss of oil where off-setting with a fewer number of wells.

The area of the lost territory thus outlined must now be computed as well as any territory which may be gained from the neighbor. This may be done by making this construction on cross-section paper, counting the number of squares or fractions of squares included in the area. A more exact method is to compute the area of the triangles by the well-known formula of the base times one-half the altitude. In the event that the area is polygonal instead of triangular, it is divided into triangles and the area of each computed and added together.

In unusually shaped leases, it is well to plan several methods of placing wells. If the cost of wells, the price of oil, and the royalty are fairly constant, it is quite possible to construct tables showing how much production to the acre the lease must have to warrant the drilling of a particular, extra well. The tremendous loss occasioned by the cutting up of an oil or gas pool into many small holdings will be discussed later under the head of large versus small companies.

In some formations the first well drilled in a group tends to set up drainage channels and to divert large quantities of oil from a considerable area. Subsequent wells come in as much smaller producers than the original well. Again, in loose, unconsolidated sands, such as are found in the Caddo field in Louisiana, if a well stops pumping for a day, the surrounding wells extend their own channels, sometimes permanently and seriously reducing the production of the well that had stopped pumping.

In certain lenticular formations, described by the oil man as "spotty," of two wells drilled only 150 feet apart, one has been a large producer and the other a dry hole. Again in the Caddo field, wells are in places so closely connected underground that the muddy water used in drilling one well is said to have been pumped out from another a considerable distance away, and in a few cases from a well that was not the nearest to the one being drilled.

In the Vinton pool in Louisiana a well drilled near a good producer encountered a coarse pay sand, so loose that the rotary bit of its own weight immediately sank to the bottom. A second well struck sand, seemingly of the same nature, which immediately "packed," so that drilling was necessary to penetrate it. The second well never produced; moreover the sand "packed" in the original well, which likewise ceased to produce.

CHAPTER XI

OIL AND GAS LANDS

When the operator has selected land which is geologically indicated as being worth prospecting, he must next obtain the right to develop this land. This he may do in one of three ways, viz.:

(*a*) By purchasing the land.
(*b*) By purchasing the oil and gas right.
(*c*) By leasing the oil and gas right.

The differences in regard to deed and lease forms in the various states, together with the changes made necessary by new decisions, permit of only cursory treatment here. Whatever the lease form it should be approved by a competent attorney specializing in oil and gas leases in that particular state. Furthermore, he should be instructed to report whenever a change in the lease form becomes advisable.

To buy the land is not ordinarily desirable if it has an agricultural value or is useful for building purposes, as this engages too much capital. Since pumping stations and tank farms are not infrequently erected near producing wells, it sometimes happens that the land which was bought primarily for such use turns out to have an oil and gas value as well.

Where the surface is of very little value, so that it can be bought at only a slight advance over the price of the oil and gas right, it should be bought. Then all questions of damage or conflict with workers of other mineral products, danger of pollution of springs, etc., are avoided.

It sometimes happens where land is remote from production, that it can be bought cheaper than the oil and gas right, for a land owner generally increases his estimate of the value of the mineral rights of his land when he knows that a producer desires it for oil or gas purposes. This is because he credits the producer with having information or methods unknown to him.

The oil or gas right can be obtained either by purchase or lease. There are several very important advantages in owning the oil or gas right (with or without the surface), as opposed to leasing:

(1) One is not hurried into drilling prematurely.

(2) The holding is more secure in this period of uncertainty as to the legal status of leases.

The second advantage is important since the courts have taken their present attitude toward the surrender clause, and since the renewable option type of lease is not yet firmly established. When courts hold that leases are to be construed "most favorably for the lessor,"[1] and even go so far as to say that the holder of the lease must drill earlier than the express provisions of the lease indicate or else lose the lease, then it is seen how ill adapted the current lease forms are to the requirements of the industry.

An old decision that the oil or gas under a tract of land cannot itself be sold has unfortunately led producers to neglect the purchase of oil rights. This decision, however, merely requires the use of more precise language[2] as in any one of the following forms:

(*a*) "grant and demise to the said grantee the exclusive right to enter thereon at all times for the purpose of operating thereon for oil and gas, and does grant and demise all oil and gas that may be produced by operations upon said land, etc."

This language is similar to that of the lease, the essence of the difference being that in one case the original payment is the consideration, while in the other an important part of the consideration is in the form of a royalty on the oil and gas to be produced, or else a rental for the amount produced in each year.

(*b*) "grant and demise unto the said grantee all the following real estate . . . , always saving, reserving and excepting to the grantor the surface and the use of the surface excepting such as may be necessary for the said operations of the grantee."

(*c*) "grant and demise unto the said grantee all the mineral, expressly including oil and gas, which may be produced by operations upon said lands."

The consideration in this transfer is fixed, rather than in the nature of a royalty, and the producer is in this way freed from interference as to the time of drilling his wells, which is the great desideratum. Nevertheless, the advantage of having some contingent element may be retained by inserting a provision for deferring part of the payment to a series of five or ten annual payments or equivalent quarterly payments, with the proviso that "This transfer shall be null and void should any one of these payments be defaulted."

The operator, owning a partially or wholly developed lease, frequently finds that the royalty interest can be bought to advantage. He should calculate the value of the royalty to himself, not overlooking the advantages from saving in tanks, offsetting, etc., and should attempt to

Owen v. Corsicana Pet. Co. (Texas Appeals), 1695 Southwestern 192, p. 198.

Kahle v. Crown Oil Co., 100 Northeastern 681.

negotiate a sale. If he fails, then he should keep an offer before the lessor. The latter will often sell at some later time, as he sees how his royalties dwindle and wants the actual cash for some need that arises.

The following lease form typifies one of the two older types in current practice:

Oil and Gas Mining Lease

This Indenture Made this......day of......A. D. 191...., by and between .... of .... party of the first part, and the.. ....a corporation of Bartlesville, Oklahoma, party of the second part,

WITNESSETH: That first party, for and in consideration of the sum of....... ....Dollars ($................) unto first party well and truly paid by second party, at or before the signing and delivery hereof, the receipt whereof the first party does hereby acknowledge, has granted, demised and let, and by these presents does grant, demise and let unto the second party, all the oil and gas in and under the following described tract of land, and also the said tract of land itself, for the purpose of operating thereon for oil and gas, with the right to use water therefrom and with all rights and privileges necessary or convenient for conducting the said oil and gas operations, and for the transportation of oil and gas from and over the said tract of land, and waiving all right to claim or hold, as fixtures or part of the reality, any of the property and improvements which second party may place or erect in or upon said land, and agreeing that all such property or improvements may be removed by second party at any time before or after the termination hereof. The said tract of land is situate in .... County, State of Oklahoma, and is more particularly described as follows: —

....

....

....

....

Section....., Township.......... North, Range......... East, containing....... acres, more or less; but no well shall be drilled within................ feet of the present buildings on said tract of land without the consent of first party. First party expressly releases and waives all rights under and by virtue of the homestead exemption laws of the State of Oklahoma.

TO HAVE AND TO HOLD The same unto the said party of the second part, its successors and assigns, for the term of ten years from the date hereof, and as much longer as oil or gas is found in paying quantities, excepting and reserving to first party the.......................... part of all the oil produced and saved from the said premises to be delivered into the pipe line to the credit of first party free of cost, and should any well produce gas in sufficient quantity to justify marketing the same, second party shall pay therefor at the rate of........................... Dollars ($........) per annum, payable within thirty days from the time that gas is used therefrom, and yearly thereafter for such time as gas therefrom is so marketed. And first party shall also, so long as gas is so utilized, have gas free of cost sufficient for............ stoves and ....lights in one dwelling house on said tract of land, such gas to be delivered to first party at the well, and all pipe or connections therefrom to the dwelling house to be laid and made by first party; second party shall also have the right to use sufficient gas, oil or water from the premises to run all necessary machinery for drilling or operating its wells on said land.

Second party agrees to complete a well on the above described tract of land within........................ from this date or thereafter pay first party a rental of...............Dollars ($.........) per quarter, payable quarterly in advance until such well is completed. All payments under this lease may be made by check mailed direct to first party at.................... or deposited to the credit of the first party in the...............Bank of.......................... ......, and any payment due hereunder made by depositing the same to the credit of first party in said bank, shall bind any subsequent purchaser of the above described land with the same effect as though said payment were made direct to said purchaser.

For the consideration above named first party also grants to second party the right at any time, upon payment to first party of...............Dollars ($......), to surrender up this lease and be discharged from all liability thereunder arising after such surrender, and upon such surrender this lease shall at once cease and determine and no longer be binding upon either party, PROVIDED, that in the event any suit or action is brought in any court by the lessee to enforce this lease, then this clause, providing for a surrender of this lease by the second party, shall become inoperative and of no effect between the parties from the time of the commencement of such suit or action.

This lease shall bind and run in favor of the respective heirs, executors, administrators, successors and assigns of the parties hereto.

In Witness Whereof, the parties have hereunto set their hands and affixed their seals the day and year first above written.

..................................(SEAL)
..................................(SEAL)
..................................(SEAL)
..................................(SEAL)

STATE OF OKLAHOMA, }
COUNTY OF...................., } SS.

Before me, a Notary Public in and for said County and State, on this........ day of................191...., personally appeared......................... to me known to be the identical person who executed the within and foregoing instrument and acknowledged to me that he executed the same as his free and voluntary act and deed, for the uses and purposes therein set forth.[1]

....
Notary Public.

My commission expires.....................

The most frequent variation is the substitution of the clause:

"to start a well within.......from this date, and thereafter pursue operations with due diligence until said well is completed."

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[1] The affidavit form differs in some states, for instance in Illinois, where the following should be added at this point "including the release and waiver of homestead."

This is in order to provide for the all too frequent fishing jobs. Or we may leave the date of completion the same, and add:

> "unless unavoidable accidents or delays postpone the completion of the well, provided that due diligence has been used in the operations and provided that the well was started at such a time as would otherwise have sufficed for its completion."

The advent of gasoline extraction from casing-head gas makes it advisable to add the following:

> "In the event that gas from wells which are producing oil is sold or used by the lessee for any purpose other than operating purposes on said land it shall be paid for at the rate of .... cents per 1000 cubic feet" (or ".................... dollars per quarter").

The wording of the surrender clause used in this lease form is a modification to meet the critical attitude[1] of the courts to all previous surrender clauses. This particular form does not seem to have come up for a decision as yet, but a decision may be expected before long.

In the interests of stability and conservation, it is important that the lease should permit some latitude as to the time of drilling, as delay may be advisable for these reasons:

(*a*) Later on, additional information may be available that would assist in locating the wells so as to decrease the chances of failure.[2]

(*b*) Over-production may make it desirable to postpone prospecting and to cut down development.

A contract providing for such latitude and permitting surrender is better adapted to this unique industry. It is just to the lessor, for, knowing that the well may not be drilled and that the rentals may not continue throughout the term, he bargains for a higher bonus than he would exact, if he were sure of a well, or that all the rentals would be paid.

But even where the bonus is nominal, he still receives a value in many cases, for by leasing he may make it possible to get the much desired test actually drilled. This is shown by the not infrequent attempts of a land owner or group of land owners to induce operators to accept a group of leases for a nominal bonus so advantageous do these land owners consider the prospect of a test to themselves.

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[1] Oklahoma Supreme Court, Brown v. Wilson, Case No. 7370.

[2] South Penn Oil Supreme Co. v. Snodgrass, 76 Southeastern 961.

Suppose the well is not drilled, but rental is paid instead. The size of rental payments in this case is proportionate to the sacrifice that the land owner makes to force early drilling. If early drilling is the essence of the contract to him, he eliminates all rental features and provides for nullification, if the well is not completed in the short term he fixes. The land owner is by no means the poor, ignorant, defenceless individual depicted in some decisions. In proportion as the surrounding lands are sought and hence have value as leases, he becomes acquainted with lease usages and he always has the resource of consulting Thornton's "Laws Relating to Oil and Gas."[1] It is only in quite undeveloped land that there is ground for considering him so ignorant, and in this case the long odds against the average prospector might well make him as much as the land owner the object of the court's solicitude.

The surrender clause should not be doomed, unless the courts are prepared to sanction in its place a renewable lease with the essential part as given below, which would suffice to keep the lease properly adapted to the nature of the industry and yet avoid certain precedents as to "unilaterality" that have been cited.

> ". . . . .for a term of. . . . .months, or as long as oil and gas are found thereon in commercial quantities. If no well has been completed at the expiration of this term, this lease shall become null and void, unless extended as hereinafter indicated. The lessee is hereby granted an option, to extend this lease for a term of three months by the payment of $. . . . .on or before the last day of its term. Further extensions may be made in the same manner, but only within a period of ten years from the execution of the lease."

A friendly suit should be instituted on such a lease for early decision. The following lease form, though it does not avoid the difficulties as satisfactorily as the paragraph above, has, nevertheless, recently come into extensive use. It is based upon the principle of a renewable option and has no surrender clause. The statement that the lease has a term of ten years is objectionable and the word "rental" should be avoided. It could be further improved by providing for payments wholly upon a quarterly, rather than an annual, basis. The more even process of renewal permits a better adjustment of the time of drilling or of dropping the lease.

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[1] Decisions rendered since the second edition are collected and indexed in the series issued by the Bureau of Mines entitled "Abstracts of Current Dimensions on Mines and Mining," Bull. 61, 79, 90, 101, 113, and 118. New members appear two or three times a year.

OIL AND GAS LEASE[1]

AGREEMENT, Made and Entered into the ....day of ....191....
by and between ....
....
of... hereinafter called lessor (whether one or more), and.......................... hereinafter called lessee.
WITNESSETH, That the said lessor, for and in consideration of........DOLLARS cash in hand paid, receipt of which is hereby acknowledged, and of the covenants and agreements hereinafter contained on the part of lessee to be paid, kept and performed, ha....granted, demised, leased and let and by these presents do.... grant, demise, lease and let unto the said lessee, for the sole and only purpose of mining and operating for oil and gas, and laying pipe lines, and building tanks, powers, stations and structures thereon to produce, save and take care of said products, all that certain tract of land situate in the County of.....................
State of Oklahoma, described as follows, to wit:
....
....
of Section............Township............Range................and containing....................acres, more or less.

It is agreed that this lease shall remain in force for a term of.................. years from this date, and as long thereafter as oil or gas, or either of them, is produced from said land by the lessee.

In consideration of the premises the said lessee covenants and agrees:

1st. To deliver to the credit of lessor, free of cost, in the pipe line to which it may connect its wells, the equal one-eighth part of all oil produced and saved from the leased premises.

2nd. To pay the lessor.. DOLLARS each year in advance, for the gas from each well where gas only is found, while the same is being used off the premises, and lessor to have gas free of cost from any such well for........stoves and..........inside lights in the principal dwelling house on said land during the same time by making..........own connections with the well at..........own risk and expense.

3rd. To pay lessor for gas produced from any oil well and used off the premises at the rate of..............................DOLLARS per year, for the time during which such gas shall be used, said payments to be made each three months in advance.

4th. If second party does not commence at least one well upon the said premises within..........year....from the date hereof, this grant shall thereupon become null and void, unless second party shall pay to first party the sum of..............
........Dollars for each year the commencement of the said well is thereafter delayed, payable quarterly in advance, and upon the payment of the said sum of

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[1] "Ohio Special" — Published by Burkhart Printing & Stationery Co., Tulsa, Okla.

............................Dollars per annum, quarterly in advance, this grant shall be continued in full force and effect so long as such quarterly payments are made. And it is understood and agreed that the consideration first recited herein, the down payment, covers not only the privileges granted to the date when said first rental is payable as aforesaid, but also the lessee's option of extending that period as aforesaid, and any and all other rights conferred.

Should the first well drilled on the above described land be a dry hole, then, and in that event, if a second well is not commenced on said land within twelve months from the expiration of the last rental period which rental has been paid, this lease shall terminate as to both parties, unless the lessee on or before the expiration of said twelve months shall resume the payment of rentals in the same amount and in the same manner as hereinbefore provided. And it is agreed that upon the resumption of the payment of rentals, as above provided, that the last preceding paragraph hereof, governing the payment of rentals and the effect thereof, shall continue in force just as though there had been no interruption in the rental payments.

If said lessor owns a less interest in the above described land than the entire and undivided fee simple estate therein, then the royalties and rentals herein provided shall be paid the lessor only in the proportion which..........interest bears to the whole and undivided fee.

Lessee shall have the right to use, free of cost, gas, oil and water produced on said land for its operations thereon, except water from wells of lessor.

When requested by lessor, lessee shall bury its pipe lines below plow depth.

No well shall be drilled nearer than 200 feet to the house or barn now on said premises.

Lessee shall pay for damages caused by its operations to growing crops on said land.

Lessee shall have the right at any time to remove all machinery and fixtures placed on said premises, including the right to draw and remove casing.

All payments accruing under this grant may be made in cash direct to first party, or either of them, or by check mailed to them, or either of them, or such payment may be made by depositing the same in the.................................... ....Bank of .... to the credit of and subject to the order of the first party. And any and all successors to the title of first party shall hereby take notice that payments hereunder shall continue to be made to the first part..........in manner aforesaid, until second party is served with a written request from first part..........to make payment to other parties, and that all payments so made to first party shall be binding upon................successors in title until such written request is served upon second party.

First party hereby releases and waives the benefit of all rights under and by virtue of the homestead exemption laws of the State of Oklahoma.

If the estate of either party hereto is assigned, and the privilege of assigning in whole or in part is expressly allowed — the covenants hereof shall extend to the assigns and successive assigns, and it is hereby agreed that in the event this lease shall be assigned as to a part or as to parts of the above described lands and the assignee or assignees of such part or parts shall fail or make default in the payment of the proportionate part of the rents due from him or them, such default shall not operate to defeat or affect this lease in so far as it covers a part or parts of said lands upon which the said lessee or any assignee thereof shall make due payment of said rental.

Lessor hereby warrants and agrees to defend the title to the lands herein described, and agrees that the lessee shall have the right at any time to redeem for lessor, by payment, any mortgages, taxes or other liens on the above described lands, in the event of default of payment by lessor, and be subrogated to the rights of the holder thereof.

....

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In Testimony Whereof We Sign, this the..........day of..........191......

The proper relations between the land owner and the producer should be viewed from the standpoint of the oil industry as a whole, not merely from the standpoint of the land owner or the producer. The industry requires refineries and pipe lines. These are most efficient when the supply of oil is most constant. Unfortunately, this constancy is interferred with by the fact that at infrequent intervals, new pools come in very suddenly, and soon begin to decline. The terms of the lease should, therefore, be such as will tend to steady this spasmodic course of production.

The lease which permits delay of drilling for a rental has a steadying effect, for wells can then be drilled when conditions are most propitious. But such leases are impossible without surrender clauses, or, lacking these, optional renewal clauses. When such clauses are eliminated, and the industry is forced to a short lease basis, there are two serious losses. First, there is the heavy loss in repeatedly sending out leasers to get new leases when the old expire. Second, premature drilling is forced by the fear that the old lease may not be renewed. The gradually increasing rental in the Indian lease has the same fault. It "puts the screws on" the operator to force him to drill early, which, in the light of available information and the condition of the oil market, may be premature and so offend sound principles of conservation. Long term leases are necessary to protect projected refineries and pipe lines by insuring lands for continued development.

In wildcatting, where it is desirable to have one well "hold" as much acreage as possible, a "wildcat lease" such as the following has been used. However, there are a number of points involved that are not well established, and such forms must therefore be used with caution and with full knowledge of the latest pertinent decisions. An additional reason for caution in the choice of lease forms is that, in case of sale, the form may not prove acceptable to the attorneys of possible prospective purchasers. On the other hand, the advantage of such a lease form is not important, because when wildcatting with the regular lease form, an agreement may be made that the lease shall be held in escrow until one well is drilled in the region by the lessor within one year. Under these circumstances, the land owners would probably make as favorable terms as could be obtained with a wildcat lease form.

WILDCAT LEASE[1]

WHEREAS, ... the owner of certain lands situate in................County, Oklahoma, proposes to lease same for oil and gas purposes; and

WHEREAS, ...is desirous of leasing same for the purpose of exploring for oil and gas; and

WHEREAS, the drilling and exploring for oil and gas on the lands hereinafter described is what is known among oil and gas operators as "wildcatting," no drilling for oil or gas having been done within many miles of said lands; and

WHEREAS, ... along with many other citizens of ....County, Oklahoma, propose to make oil and gas leases on their lands to ....for the purpose of getting a test well put down in the vicinity of their lands and within four miles of same, to ascertain whether or not there is oil or gas underlying same; and

WHEREAS, it is the understanding among many of the land owners in that portion of............County, where said lands hereinafter described are situated, that the drilling of a test well will tend to greatly enhance the value of their lands, whether said test well is drilled upon the lands described in this lease or some other lands situated in the vicinity of and within a radius of four miles of same; and

WHEREAS, it is mutually agreed and understood by said.................... and... the lessor and lessee.... herein, that the drilling of a test well as hereinafter provided, whether the same be drilled on the lands described in this lease or on other lands in the vicinity of the lands described herein and within a radius of four miles of same, shall be one of the considerations for this lease and shall be in full satisfaction of all obligations due the lessee during the first year of this lease.

NOW THEREFORE, THIS AGREEMENT, made and entered into the......... day of.........., A.D. 191...., by and between........................party of the first part, and.. of............, Oklahoma, party of the second part.

WITNESSETH, That the said part......of the first part for and in consideration of the sum of..............................Dollars, to........in hand well and truly paid by the said party of the second part, the receipt of which is hereby acknowledged, and the covenants and agreements hereinafter contained on the part of the party of the second part, to be paid, kept and performed, hereby grant, demise, lease and let unto the said party of the second part, ...heirs or assigns, for the sole and only purpose of mining and operating for oil and gas, and of laying pipe lines, steam, water, gas and shackle lines to and from adjoining land, and of build-

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[1] "Form 22" — Published by Burkhart Printing & Stationery Co., Tulsa, Okla.

ing tanks, stations and structures thereon to take care of said products, with the right of going in, upon, over and across land for the purpose of operating the same; also the right to sub-divide and re-lease the same or any part thereof, all of the following described tracts of land, to wit: the....................................
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of Section..........Township..........Range..........in..........County, Oklahoma, and containing....................acres, more or less.

IT IS AGREED that this lease shall remain in full force for the term of.......... years from this date and as long thereafter as oil or gas, or either of them, is produced therefrom in paying quantities by the party of the second part, his heirs or assigns.

IN CONSIDERATION OF THE PREMISES, the party of the second part covenants and agrees: First — To deliver to the credit of the first party, his heirs or assigns, free of cost, in pipe lines to which they may connect their wells, the equal one- ....of all oil produced and saved from the leased premises. Second — To pay to first part...................heirs or assigns, one hundred and fifty ($150) dollars per year for the gas from each and every well drilled on said premises, the product from which is marketed and sold off the premises and payment to be made on each well within sixty days after commencing to use the gas therefrom, as aforesaid, and to be paid yearly thereafter while the gas from said well is used. First party to fully use and enjoy the premises for farming purposes except such parts as may be used by second party for the purpose aforesaid, second party agreeing to locate all wells so as to interfere as little as possible with the cultivated portions of the farm. First party to have the right and privilege of using at...........own risk sufficient gas for one dwelling house on the premises from any well on said described lease, ...to make ....own connections, and it is agreed that no well shall be drilled within...............feet of the building now on the premises without the consent of the first party.

The lessee hereby agrees and binds himself, his heirs or assigns, to drill a test well on the lands herein described or on the lands in the community where the lands herein described are situated, and within a radius of four miles of same, to a depth of.. (....................) feet, unavoidable accidents and delays excepted, or unless oil and gas or what is known as the Mississippi Lime are found at a less depth.

It is expressly agreed and understood by the parties to this lease that the drilling of a test well by the lessee, his heirs or assigns, on the lands described herein, or on any other lands in the community where the lands herein described are situated, and within a radius of four miles, shall be a consideration of this lease, whether same be a producing well or a dry hole, and the drilling of such well at any time within one year from the date hereof, shall be full satisfaction and discharge of all obligations of the lessee due hereunder for and during the first year of said lease, and if said test well is not drilled within one year from the date hereof, this lease shall become null and void and of no effect.

It is expressly agreed and understood that if a test well is not drilled on the lands described herein, but is drilled on any other lands in the vicinity where the lands herein described are situated and within a radius of four miles of same, then and in that event, the lessee herein agrees to drill a well upon the lands herein described within two years from the date hereof, or this lease shall become null and void, however, this lease may be continued in full force and effect, if said second party shall pay to said first party, a rental in the sum of $................for each and every twelve (12) months the drilling of said well is delayed after the expiration of the second year. But if said test well or other well is drilled on the land described herein, whether the same be a producing well or a dry hole, it shall be in full satisfaction of all rentals due hereunder for the full term of this lease.

All rentals that become due hereunder to the lessor may be deposited in the ....Bank of................to the credit of said lessor and a tender of said amount at any time to said bank shall be considered a tender to the lessor.

IT IS HEREBY AGREED, That the party of the second part reserves the right to discharge any incumbrances against the lands described herein and have a lien thereon for the amount so paid. The party of the second part shall not be bound by any change in the ownership of said land until duly notified of same, either by registered letter duly signed by parties of the first part, or by receipt of original instrument of conveyance, or a duly signed copy thereof.

It is agreed that the second party is to have the privilege of using sufficient water, oil and gas from the premises to run all necessary machinery, and at any time to remove all buildings, machinery and fixtures placed on said premises, including the right to draw and remove casing.

The party of the second part, his successors or assigns, shall have the right at any time on the payment of..DOLLARS to the party of the first part,................successors or assigns, to surrender this lease for cancellation, after which all payments and liabilities thereafter to accrue under and by virtue of its terms shall cease and determine; provided, this surrender clause and the option therein reserved to the lessee shall cease and become absolutely inoperative immediately and concurrently with the institution of any court of law or equity by the lessee to enforce this lease, or any of its terms, or to recover possession of the leased land, or any part thereof, against or from the lessor, his heirs, executors, administrators or assigns, or any other person or persons.

All provisions hereof shall extend to the heirs, successors and assigns of the respective parties hereto.

IN WITNESS WHEREOF, Said parties have hereunto set their hands and seals the day and year aforesaid.

Royalty

The rate of royalty is ordinarily a fixed one, although the conditions alter so much with the age of the well. The rate is usually expressed as one of the following fractions: $\frac{1}{10}$, $\frac{1}{8}$, $\frac{1}{6}$, $\frac{1}{5}$ or $\frac{1}{4}$ with $\frac{1}{8}$ the most common. The difference between $\frac{1}{10}$ (10 per cent) and $\frac{1}{8}$ ($12\frac{1}{2}$ per cent) is only $2\frac{1}{2}$ per cent, yet the difference between $\frac{1}{5}$ (20 per cent) and $\frac{1}{4}$ (25 per cent) is 5 per cent. These differences are not as fully realized as they should be. The negotiator should keep in mind the percentage equivalents of the fractional rates and their differences as shown in the accompanying table, since they give a truer idea of the real differences. There is no good reason why intermediate rates expressed as percentages should not be used if desired.

A COMPARISON OF ROYALTY RATES

Fraction.	Percentage.	Difference in percentage.
$\frac{1}{2}$	50	
$\frac{1}{3}$	$33\frac{1}{3}$	16.33
$\frac{1}{4}$	25	8.33
$\frac{1}{5}$	20	5.00
$\frac{1}{6}$	$16\frac{2}{3}$	3.33
$\frac{1}{7}$	$14\frac{2}{7}$	2.29
$\frac{1}{8}$	$12\frac{1}{2}$	1.79
$\frac{1}{9}$	$11\frac{1}{9}$	1.39
$\frac{1}{10}$	10	1.11
$\frac{1}{11}$	$9\frac{1}{11}$	0.91
$\frac{1}{12}$	$8\frac{1}{3}$	0.76

Since the conditions alter so greatly during the life of a well, it is surprising that sliding[1] royalties are so uncommon with oil wells.

Royalties may be graduated in three ways:

(1) In the *class* method the wells are classified, some paying a higher royalty and some a lower royalty from the beginning. The classification may be based on the amount of the income as produced either by the differing size of individual wells, or by the differing value of the oil because of quality. It is desirable that the royalty should be less than one-tenth where the production is so small as to make operating scarcely worth while. Similarly, it should be less when it is known that the oil is of particularly low grade, so that the wells, when their size is considered, are scarcely worth drilling.

Again, the classification may be based on the cost of production. For instance, the one-sixth charged in the Osage is absurdly high for the Western Osage deep sands, some of which are found deeper than 3000 feet. The land owner may induce operators to produce from deep sands that do not otherwise pay even with a nominal bonus, by making a concession as to royalty.

(2) In the *progressive* method the rate may be made to increase by steps or uniformly. In either case, it is wholly unadapted to oil and

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[1] Johnson, Roswell H. Sliding Royalties for Oil and Gas Wells. Trans. Amer. Inst. Min. Eng., Vol. 52, pp. 322–328.

gas production, since production gradually decreases, and abandonment occurs when the income has declined to the outlay. Thus the progressive method of royalty payment would operate against the principles of conservation by causing premature abandonment of wells.

(3) The *degressive* method (a term used in taxation) reduces the rate by steps or uniformly, and so succeeds in keeping the well productive for a longer time. It is, therefore, very desirable.

The degression may be accomplished by the block, period or uniform plan.

In the block plan, the oil pays a certain royalty till a given number of barrels have been produced, and thereafter pays less. There may be only the one step, or as many more as are specified. The fault of this plan is its lack of adjustment to the maintenance cost, since the change might come long before or after the time when income equals outlay. It is this adjustment that is the main object of the degressive method.

In the period plan, the well changes its royalty after a definite length of time, or after the production has been reduced to a specified amount. The disadvantage of the definite period is the same as that of the block method. The disadvantage in using the time when the well has declined to a specified production is the indefiniteness. This would cause friction between lessor and lessee in fixing the time, since the curve of decline does not have a mathematical smoothness, but is influenced by the exigencies and the mode of operation.

In the uniform plan all sudden changes are avoided by providing that all the production less than a certain amount per week has one rate of royalty, or none at all, and the oil produced in excess of that amount pays an additional rate of royalty. In the interests of avoiding complication and excessive calculation, the method is here recommended in which there is only the usual rate with a small amount of oil production exempt.

The fear has been expressed that if sliding royalties are adopted, too steep a graduation might be used, which would have the effect of destroying the occasional high rewards essential to recoup the producer for the heavy expenses of the inevitable proportion of dry holes. If the producer is deprived of these rewards, the cost of oil to the consumer is naturally increased, as higher profits on average wells would be necessary to furnish incentive to the producer to continue his activities. Such a result would be a social loss, but the fear in our opinion is not justified, for the land owner would not get such steeply sliding royalties without serious sacrifice in the bonus, which he would usually prefer not to make.

Another advantage of the degressive royalty is to prevent the excessive flat royalties now frequently offered for unusually promising land, such as 50 per cent on the Cimarron River bottoms and the 25 per cent that we occasionally hear of in other rich fields. These royalties always lead in a few years as the production declines to unpleasant threatening and bargaining between land owner and lessee, resulting in successive agreements to reduce the royalty rate. This awkward process, it is true, does accomplish a gradual reduction of the royalty rate. But the asperities of such negotiations are very annoying and sometimes lead to premature abandonment of a well. The degressive royalty, while avoiding the difficulties just referred to, still retains a flexibility by virtue of which the producer, who desires to, may increase the royalty rate, during the time only when the well can "stand it." In this simple way some of the speculative profits may be transferred to the land owner in lieu of bonus where the producer may not be able to pay it, or the land owner may prefer not to accept it.

The degressive royalty lengthens the life of the well and increases the percentage of the oil which is recovered. If the royalty is one-sixth and the maintenance and interest on the "junk" is 83⅓ cents per day, then a well must be abandoned when its net income to the producer reaches that amount. Yet the gross income is still $1.00 per day, and if the decline of the well is one-sixth in a year (a common decline in old wells in Oklahoma) it might have produced for a year longer except for the royalty. Thus, for instance, 300 barrels per well in some cases might easily be saved by a mere royalty adjustment. In the Osage Nation, which is leased at one-sixth, all the wells are prematurely abandoned. More probably, however, here as elsewhere, the Department of the Interior will see that it is hurting the interests of the Osage Nation as well as offending against conservation by forcing these early abandonments. The department will either adopt a degressive plan for these leases or else go through the usual awkward and vexatious process of making repeated reductions as described above.

In fixing the amount of exempted oil, the ideal is to permit the well to be pumped until its gross income has fallen to its outlay. To accomplish this, we suggest an exemption from royalty on the oil equal to maintenance and interest on the junk during the last years of the well. The slight loss to the land owner will be met ordinarily in the bonus, but sometimes by a higher royalty on the first 1000 barrels produced.

For practical reasons the amount that should be exempted, instead of being exactly equal to maintenance and interest on the junk, would be fixed for the field at the nearest integral number of barrels per day, ordinarily one. When several wells discharge into one field tank and do not differ greatly in size and age, they may be averaged.

The objection which might be raised that the land owner would receive nearly nothing for the use of the land during the last months of the history of the well is met by the fact that he has received advance payment for such use either in bonus or as royalty during the earlier history of the well.

Gas Royalties

In some fields gas may be so cheap and wells so isolated that it is still infeasible to meter from the lease, but fortunately the payment of gas royalty is steadily replacing gas rentals. Where gas royalty is paid, the general principles laid down for oil apply in even a greater degree to gas production. Frequently a gas well is abandoned because its output is not enough to pay the fixed rental for a well. Also the small wells about to be abandoned have a disproportionately heavy maintenance cost by reason of the necessity sometimes of pumping water, or more often of installing pumping stations.

To meet this situation we recommend for gas wells a stated royalty rate, with the exemption of a certain amount of gas per week, roughly estimated in advance, equivalent to the cost of maintenance and the interest on junk. This exemption is to be increased when water pumps are installed at the well or pumping plants are required to raise the pressure sufficiently to put the product into the main lines.

Errors in Leases

In filling out a lease two omissions are common and may be the cause of much annoyance. The lessor's name should be given as "John Doe, single," or "Richard Roe, widower," as the case may be. Or if he is married, the wife should join in the lease. The word "single" makes it unnecessary to inquire why his wife did not join in the lease. Again, the lease description should be carefully checked by a second party. Confusion is extremely likely to arise in writing or reading land descriptions, even in the minds of experienced persons.

The lease should be recorded promptly at the office of the Recorder of Deeds, or at the corresponding office in the county where the land lies, except in a few cases, where for the sake of secrecy it may seem best to wait and record the whole group of leases on the first day when other necessary actions make publicity inevitable.

To find all the owners of desired land, with a minimum of time and expense, requires considerable ability on the part of the leasers. Further ability is necessary in organizing the leasing so that some individual land owner will not hold out unfairly and profit by the testing which has been brought about by the willingness of his neighbors to lease.

Coöperation

There are various kinds of coöperation between producers in regard to leases which are mutually beneficial:

(1) The leases may be taken jointly. This is very desirable when two companies find themselves wasting time and labor seeking leases in the same area at the same time. They may take the leases jointly, waiting until the leases are all in hand before the decision is made how to divide the leases between them, or whether one is to sell or trade for other leases. Or they may even decide to operate jointly.

(2) One company, usually the one better provided with working capital, operates the property with a half or a minority interest held by the other. The necessary calls for working capital may be met wholly by the operating company "having an interest carried" or by each company pro rata. This arrangement is more common where the operating company is affiliated with a pipe line company, and the participating company is the one that held the early leases.

(3) One company proposes to drill a test, if the owners of the neighboring leases will contribute to the cost of the well. However, if it is successful, then the drilling company meets the whole expense.

(4) One company receives from neighboring companies contributions of leases as an inducement to drill a well at its own expense.

(5) One company having obtained a large group of leases, guarantees that it will drill at a certain point. The enhancement of the value of the leases, from the assurance of the test, makes it possible to sell enough of these leases at an advanced price, so that the receipts will pay a large part, sometimes even all of the expense of the well.

(6) The company owning the lease pays the contractor who drills the well with a part interest in the lease.

Restricted Leases

The land may not be held by individuals free to lease as they please. There are the following cases:

(*a*) The land is held by a minor. Such land can be leased by the guardian with the court's sanction only during the minority of the owner, except in special cases. In the case of oil and gas, this is of course a serious limitation. The property must be so good, that, in spite of the short term, the producer can risk being able to make a satisfactory release when the owner reaches his majority. If the lease is being drained and the owner is within a few years of his majority, the court may authorize the guardian to grant a lease for a term extending as long as oil and gas are found in paying quantities, since it is necessary in that case to protect the ward's property in this way.

(*b*) The land is held by an incompetent. The lease made by the guardian must be approved by the court.

(*c*) The land is owned by an Indian whose rights in the land are restricted. The form of lease in these cases is prescribed by the Indian Office, and each specific lease must be approved by it, and a bond must be filed.

(*d*) The land or the oil and gas rights are held by the tribe collectively. The leases in this case are made on a form adopted by the Tribal Council under the guidance of the Indian Office. The important instance is that of the Osage Indians in Oklahoma, more than half of whose land is not now leased. The drilling conditions and other terms of the lease form in the bidding for Osage land near Cleveland, Oklahoma, were so severe, and the parcels so unjustifiably small, that the large number of simultaneous dry holes, the result of improperly forced drilling, caused an unwarranted loss to the producers.

The most efficient and beneficent development of the unleased Osage Nation can be accomplished by the Oliver Plan.[1] In this plan the tribe, with governmental guidance, will describe the lands and publish maps and reports as to the possibilities of oil, and arrange a form of lease to one general company. It will thereupon call for subscriptions of stock to such a company, the amount to any one stockholder being limited. If an adequate amount is subscribed, the paid-up stockholders meet and choose their board of directors. If the amount is over-subscribed, the stock is apportioned pro rata.

Public Lands

Most of the public lands which seem promising for oil and gas have been withdrawn from entry, since there is universal agreement by both government and producers that the present law, by which oil and gas lands are taken as placer claims, is utterly unadapted to the industry.[1]

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[1] Proposed by Earl Oliver. Hearing before the Committee on Public Lands, U. S. Senate, 63d Cong. 3d Session on H. R. 16136.

The development of the lands which are not withdrawn would best be postponed until a new oil and gas prospecting permit and leasing law is passed, and the oil placer claim law revoked, except where work is already started. Since this may be expected in December, 1916, the description of the procedure in taking oil placer claims is omitted here.[2] The Oliver Plan, briefly described on p. 112, is that best adapted to the public lands. The tract should be large enough to supply a large refinery for a long period. If possible it should be a geological unit, so that there would be a minimum chance that any pools would overlap the boundaries of the property. If the plan adopted is along the lines of the Ferris Bill which has passed the House providing for licenses to prospect small tracts, then, in order to avoid over-production, all the public lands should not be thrown open at once, but only specified regions from time to time, where and when the local price of oil is high. The greatest dangers lie in (*a*) making the licensed units too small to warrant the necessary examination and drilling to the proper depth and (*b*) giving preference by the device of posting a notice[3] on the claim, which encourages fraud and irresponsibility.

Unfortunately a custom has grown up in Wyoming and Montana of drilling shallow holes on placer claims just deep enough to get a color of shale oil, with the idea that this "validates" the claim. Such "fake" holes should not and doubtless will not give grounds for patenting.

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[1] Ball, Max W., Trans. A. I. M. E., 48, pp. 451–470.

[2] Ball, Max W., "Petroleum Withdrawals and Restorations," U. S. G. S. Bull. 623; U. S. Bureau of Mines Bull. 94.

[3] Johnson, Roswell H., Oil and Gas Journal, Feb. 24, 1916, p. 26.

CHAPTER XII

DRILLING FOR OIL AND GAS

For a complete description of the actual operations and apparatus used in drilling and casing oil and gas wells, the reader is referred to Westcott's "Handbook of Natural Gas," Paine & Stroud's "Methods of Oil and Gas Production," Bowman's "Well-Drilling Methods[1]," and the catalogue of the various supply companies. The present authors have restricted themselves mainly to a discussion of the choice of methods and comparative costs of the different methods in those fields where both systems are used.

Drilling methods. — While from time to time in the history of the petroleum industry, various methods of drilling have been developed to suit particular needs, these are all modifications of the two general systems in use today in North America, viz., the standard or churn-drill system, and the rotary system. Their various modifications, such as the Canadian pole-tool system and others, are principally of interest from a historical standpoint. The two systems mentioned are seldom used side by side in the same field, except in some districts in California, but have been developed to suit different needs as new fields were opened. The rotary method was first used for oil well drilling by Captain A. F. Lucas in Texas to drill in the soft Quaternary and Tertiary formations of the Gulf Coast. These formations caused so much trouble to the drillers, using standard tools of the Appalachian fields, that it was practically impossible to proceed. At the same time it is true that a few districts, where the rotary system is better adapted, were developed by men from the Appalachian fields with cable tools with which they were more familiar. Operators are frequently loath to change from accustomed methods unless conditions absolutely demand such a departure, and when one system is well established in a field, the initial expense of drilling a well by a rival system is so much more than by the familiar method that inertia inevitably impedes experimentation. This is partly due to the fact that the other tools are not carried by the local supply houses, and spare parts are difficult to obtain without delay, while the supply of local labor does not answer for a class of work with which it is not familiar.

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[1] U. S. G. S. Water Supply Paper 257.

However, in California and Mexico a class of men accustomed to both systems has evolved, through the use of the so-called "combination" rigs. It is claimed that a "standard" driller who is afterward trained to the use of the rotary machine is more efficient than a man who receives his first training with the rotary. The reason for this is that the churn drill accustoms the driller to watching the variations in the formations through which he is passing, since he drills usually with a dry hole and runs the bailer frequently. He is thus accustomed to keep a better log of the well as he goes down. On the contrary, the wash from the rotary machine furnishes an obscure record as to the formations passed through, and it is difficult to keep an accurate log. Furthermore, the weight of the column of water suppresses all minor evidences of oil, gas and water. In the matter of casing, when the rotary method is used, there is less occasion for the use of the driller's judgment. Men thus trained become good mechanicians, but are unaccustomed to cope with emergencies to the extent that those are who use the cable tools.

"Standard" or cable drilling system. — This system is often called the percussion or American cable system,[1] and consists essentially of a heavy steel bit attached to a manila or wire cable, which is raised and dropped by means of a walking-beam extending over the hole.

It is adapted for drilling into hard formations or those sufficiently consolidated to permit the sides of the hole to "stand up" so that drilling may then be carried on until it is advisable to case off some water or gas bearing stratum. The Paleozoic rocks found in the Appalachian, Erie, Lima-Indiana, Illinois and Mid-Continent fields of the United States are therefore drilled by this standard system.

By using an under-reamer (Paine and Stroud) it is possible to drill in formations somewhat softer than these, following up the tools with the string of casing closely enough so that the side of the hole does not cave and prevent the tools from being withdrawn. This work is of course slow, both on account of the extra precautions and on account of the time taken, after drilling a section of the hole, to under-ream so that the casing may follow and drilling may then proceed.

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[1] Paine and Stroud, "Oil Production Methods"; Bowman, Isaiah, "Well-Drilling Methods," U. S. G. S. Water Supply Paper 257; Thompson, A. Beeby, "Petroleum Mining."

There are some districts where part of the hole stands up very well, while certain other formations in the same hole cave badly. The question then arises which system is the best to use under the circumstances. The added time and expense necessary to under-ream, plus the added chance of delay through accidents if the cable tools are lost, must be balanced against the greater cost of the rotary outfit, the difficulty of handling the harder part of the hole with a rotary outfit, the probable inaccessibility of spare parts in the local supply stores, the question of the availability of the larger supply of water necessary for the rotary, and the sparse supply and the greater cost of experienced men for rotary drilling. In the country to which each is best adapted, the rotary excels so far as the time of drilling is concerned. For instance, to drill a 2000-foot hole with standard tools in Pennsylvania and West Virginia takes about 30 days; while to drill a 2000-foot rotary hole in Louisiana takes from 15 to 20 days.

This saving in time offsets to some extent the greater labor cost per day of the rotary, which requires a crew of 10 or 11 men as against a standard rig crew of three or four men.

The heavy column of water which must be used in a rotary hole puts so much pressure upon the formations that comparatively weak or small shows of oil or gas are not indicated at the well head. Therefore the cable system, drilling with a dry hole, is better adapted for wildcatting or prospecting work, as it gives the maximum information as to the formations passed through. Once a field is located, and one can estimate the depth at which the "pay" formation will be encountered, development work can proceed with the rotary machine in case it is otherwise adapted for use in that field.

In comparatively shallow territory, a portable machine of the churn drill type is frequently used, particularly in the Mid-Continent fields. It has the advantage of being easily moved about in wildcat country where roads are bad, with less loss of time than a heavy regulation outfit. It is not adapted for handling heavy strings of casing. And for wells over 1000 or 1200 feet deep the cost per foot increases disproportionately, so that it cannot compete with a derrick rig. The time saving factor and the cheapness with which such a machine can put down shallow wells adapts it also for developing a territory where the operator is positive that his farewell sand will not exceed 1000 to 1200 feet in depth. Machines were used in developing the Newkirk field in Oklahoma, and have been largely used in wildcatting in the Shallow Cherokee district in Oklahoma. It is probable that they can be used advantageously in Missouri for testing to the "Mississippi Lime," which lies at a depth of less than 1000 feet throughout a large territory.

Rotary system. — The rotary drilling machine as used for oil well drilling consists essentially of the following units:

(1) A drilling stem (usually of 6-inch pipe), to which is attached (2) the bit or cutting tool at the lower end, provided with a hole for the circulation of water. These are rotated by means of (3) a geared turntable provided with grips, driven by power. This power is usually a gas or steam engine, but may be an electric motor. A constant circulation of a thin mud slip is kept up by a special pump down through the inside of the drill stem and the hole in the bit at the bottom of the hole, and up the outside of the stem. This not only keeps the bit cool, but carries up out of the hole the pulverized material.

As a heavy column of water is kept in the hole at all times, the sides are prevented from caving, and water and gas sands need not be cased off, as frequently happens with cable tools. This saves not only time and trouble, but also the added expense of extra strings of casing and obviates a reduction in size of the hole. It is also claimed that, due to the positive rotation of the bit, and the relative inflexibility of the stem, the rotary drills a straighter hole than the standard rig, especially in districts where the strata are much inclined. In this same connection it might be mentioned that one company found it to its advantage, when drilling in steeply inclined hard limestone, to use the Canadian pole-tool system for the same reason — that the positive rotation of the bit kept a straighter hole than when the loosely swung cable tools were used.

Where there are alternating hard and soft strata, while the cable tools might drill the former in less time, the danger of accidents in the latter and the delay in handling caves sometimes more than compensates for that advantage. The hole should then be drilled entirely with a rotary, using special bits to go through the harder portions. The development of heavier machines and of such bits as the Sharp and Hughes within recent years has extended the use of the rotary into a number of such fields. It is now claimed that the rotary can be used advantageously in any of the California fields. However, the standard cable tool system still is used widely, even in those fields, and possibly in others where it could be replaced to advantage by the rotary.

In general it may be said that the rotary is more expensive than the standard for shallow wells and very deep wells, and less so for intermediate wells, when both are operating in fields where conditions are otherwise pretty well balanced. Deep wells have recently been drilled with a rotary in California, landing 10-inch casing at a depth of 4000 feet. The ability to drill large holes to the oil sand in fields producing heavy oil and much water is an added advantage.

The following table summarizes the advantages and disadvantages of the two systems. The wise operator or superintendent knows his field so well that he can give each of these various factors its proper weight, and adopt the system best suited to the conditions. There is still enough prejudice among practical men, who have become more accustomed to one system or the other, to make their judgment in some of the new fields open to question:

STANDARD SYSTEM

Advantages

1. Less first cost of tools and rig.
2. Lower labor cost per day.
3. Less water necessary.
4. Can drill in the hardest rock.
5. More drillers available in some fields, although this is becoming less true.
6. Gives more information as to the formations passed through, and is thus better for prospecting.
7. Less cost per foot for relatively shallow wells.

Disadvantages

1. Longer drilling time.
2. Much slower when under-reaming is made necessary by caving.
3. Danger of delays and fishing troubles in soft strata.
4. When many water sands, hard to carry large hole to deep pay.
5. Greater cost per foot for moderately deep wells.
6. More casing necessary to handle caves and water sands.
7. Liability of getting crooked hole in soft formations.
8. Harder to control heavy pressures and more likelihood of "blow-outs."

Rotary System

Advantages

1. Faster drilling in soft strata.
2. Less trouble from caving and water sands.
3. Less casing used in soft formations with water and gas sands.
4. Straighter hole in deep drilling in soft formations.
5. Can handle alternate hard and soft formations, with less danger of accidents than with cable tools. This is made possible by the new bits and heavier rotary machines.
6. Can carry a large hole deeper.
7. When "drilling in," easier to control high gas pressure and prevent blowouts.

Disadvantages

1. Very slow in hard strata.
2. Greater daily labor cost.
3. Limited trained labor supply in some fields.
4. Greater cost per foot for shallow wells.
5. Does not show up smaller oil and gas pays, and important reservoirs may be passed through in prospecting.
6. More water necessary, a drawback in arid regions.

There is a recent improvement in the cable tool system which combines some of the good points of the rotary. This is the "circulating system" (Paine and Stroud), by which circulation of water in the form of a thin mud slip, similar to that used with the rotary, is maintained through a special circulating-head down through the casing and up the outside of the pipe. This is to prevent caving, to shut off gas sands by keeping a pressure on the sides of the hole, and also to mud up the walls. A wire cable is, of course, used, and part of the drillings are carried up to the surface with the circulating water; but there is a retardation of the drill in spite of this.

Combination system. — In the California fields the two systems are sometimes combined, one part of the hole being drilled by the rotary while another part is drilled by cable tools. This combination method is particularly adapted to conditions such as those in Mexico, where the upper part of the hole is drilled entirely through soft marls and shales

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[1] U. S. B. of M. Tech. Paper, Nos. 66 and 68.

with only an occasional limestone shell. The rest of the hole is drilled through hard limestones and shales. When the hard limestone is reached, the casing is set, and drilling proceeds with cable tools without further change. In some wells in California the standard tools are used only for drilling into the oil sand, in order that it may be better observed and properly managed. It has been attempted to rotate the casing, which is fitted with a special shoe, at the same time that drilling proceeds with cable tools, but this has not come into common use even in the California fields.

Comparative costs and drilling time. — In very few fields can any comparison be properly made between the standard and the rotary systems of drilling. In territory to which the rotary is adapted, the cost of drilling with standard tools is abnormally high; and in fields to which the standard system is adapted the rotary is unduly expensive.

While average drilling costs may be given for certain districts, individual wells in such districts may cost fifty to one hundred per cent higher, due to accidents or unusual underground conditions. In the several California districts comparative costs are given of drilling by both systems. These are only comparative for the given field, or other fields where conditions are similar.

It must also be said that in the early development of a property, drilling isolated wells always costs more than later wells. This is for the reason that certain items such as the entire cost of rig, casing, fishing tools, etc., must be borne by one well, while as the property develops much of this is used more than once, especially the material recovered from dry holes. This also applies to other expenses, such as part of the cost of road building, rights-of-way and other expenses peculiar to each case.

In the Eastern and Mid-Continent fields of the United States, wells are contracted for at from $0.70 to $2.00 per foot, depending upon the depth, and varying with conditions of transportation, fuel, water, caving formations and number of strings of casing necessary. The shallower wells are sometimes drilled with machines; but the greater part of the drilling in these fields is done with standard cable rigs. Wells completely equipped to produce cost the owner from $1.85 to $3.00 per foot of depth, but the average cost is between $2.00 and $2.50 per foot.

At Simcoe, Ontario, wells are contracted for at $1.25 per foot. At Port Rowan the cost of drilling and equipping a producing "gasser" is from $2900.00 to $3200.00, depending upon the amount of casing left in the hole. At Bothwell a 400-foot well averages about $500.00 to drill and equip for producing.

As contrasted with these fields, wells drilled in the Alberta fields in Canada are contracted for at from $6.50 to $12.00 per foot, for wells from 1000 to 3000 feet in depth. Recent wells probably average $10.50 per foot, and the owner usually pays for any casing left in the hole. Where drilling is on company account, wells in that field cost the owners a minimum of $7.50 per foot for a 1200-foot well, or in the case of a wildcat at a considerable distance from the railroad, a maximum as high as $25.00 per foot of depth. The initial hole drilled in the Sheep River district south of Calgary is reported to have cost $100,000.00 at a depth of 2800 feet. While several combination rigs have been used in the Canadian Foot Hills fields, all contracting here and on the plains has been done with heavy cable rigs of the California type, usually using flush-joint casing. The following are the costs at which various wells in Alberta were contracted for:

Tofield No. 2	$ 9.50
Tofield No. 3	7.50
Vegreville	9.00
Wetaskawin	10.00
Medicine Hat	$7.25 to finish 1200-foot hole with 10-inch casing. $6.50 to finish with 6-inch casing.
Pelican	Reported to have cost $25,000 each, or about $20.00 per foot.

The following tables show the average drilling costs taken from the records of a large number of wells in the California fields (Bull. 69, California State Mining Bureau):

East Side of the Coalinga Field. Standard Tools

	1330 feet.	2083 feet.	2485 feet.	2830 feet.
Total cost per foot	$11.70	$11.49	$10.28	$11.08
Casing per foot	4.00	4.11	4.21	4.80
Labor per foot	2.02	2.34	1.85	1.90
Drilling labor	1.56	2.04	1.60	1.68
Actual working time, spudding to pumping	80 days	160 days	149 days	175 days
Feet per day	16.6	13.0	16.7	16.2

Drilling crew (12 hours), 1 driller	$7.00
Drilling crew (12 hours), 1 tool-dresser	4.50
Tubing gangs (12 hours), foreman	4.00
Tubing gangs (12 hours), laborers	3.25

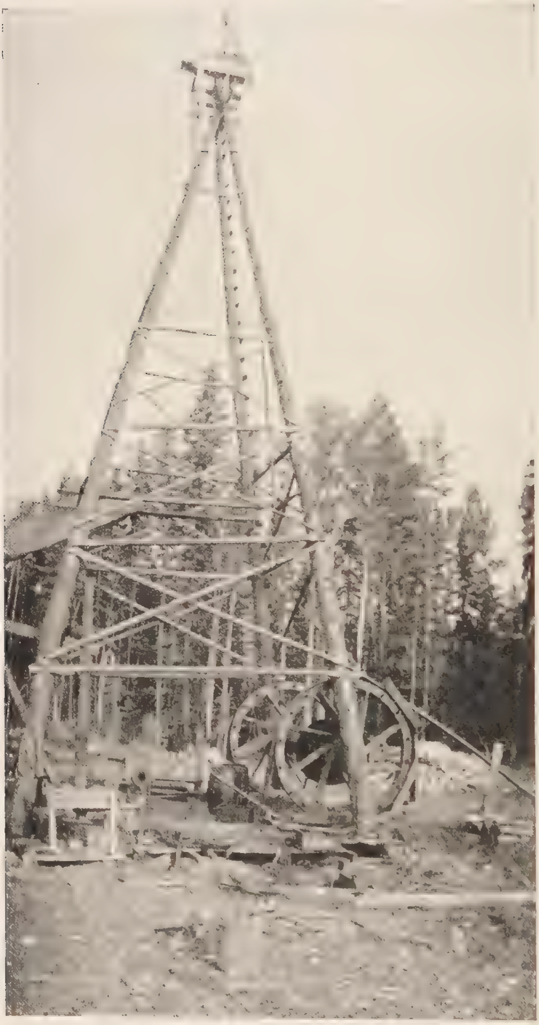

Fig 51. Pole rig used for drilling on the Athabasca River in northern Alberta, Canada.

Approximate Drilling Costs per Foot for Different Depths and Fields in California. Equipped for Pumping, Showing Drilling Systems Used

	1000 feet (Standard).			2000 feet (Standard).			3000 feet (Standard) (Rotary in Midway).		
Field.	Labor.	Material.	Total.	Labor.	Material.	Total.	Labor.	Material.	Total.
Coalinga	$2.02	$9.68	$11.70	$2.34	$9.15	$11.49	$1.90	$9.18	$11.08
Kern River	1.90	5.00	6.90	....	....	....	....	....	....
Midway, Sunset & McKittrick	1.16	6.40	7.56	....	....	....	2.48	8.38	10.86
Santa Maria	....	....	....	....	....	....	1.69	2.72	4.41
Ventura Co.	1.54	2.67	4.21	....	....	....	....	....	....
Los Angeles and Orange	....	....	....	0.78	3.06	3.84	2.22	7.50	9.72

While these averages do not show any remarkable difference in the cost of drilling of the rotary over the standard system, this can be accounted for from the fact that conditions differ so much within short distances in some of these fields, as to keep the question of relative advantage pretty evenly balanced between the two systems. But the recent improvements in the rotary system, such as improved bits and heavier machines, have increased its use and lowered the cost of drilling by this method in the California fields.

These improvements have at the same time helped drillers and operators in the Texas and Louisiana fields, where the rotary system was first developed. In the Caddo and Gulf Coast fields there is no question as to its being the best method, and in these fields the drilling time is much less and cost per foot much less than in California.

The cost of drilling by the combination system in the Mexican fields is relatively high, considering that conditions do not differ much throughout the field, and drilling and casing procedure is more or less standardized. This higher cost is due to other reasons, among the most important of which are transportation and duties, together with high labor cost, cost of maintaining camps for the men, and unforeseen delays arising from the disorganized state of the country.

Methods of casing. — There are several methods of casing, the choice of which depends upon water conditions in the strata, the system of drilling employed, the character of the formations and the depth of the hole.

In drilling by the rotary system, usually there is but one size of hole and but one string of casing used, as the sides of the hole are "mudded up" as drilling proceeds, and caving beds and minor gas and water sands are shut off in this way. However, bad caving and large flows of gas and water must sometimes be cased off, and the hole continued with a smaller size of casing. In such cases heavier casing is used than in hard rock fields, one that can resist a heavy collapsing strain from the outside.

In drilling with the cable method, water sands must be cased off to prevent flooding the lower oil formations. This should also be done in the case of upper gas sands. Caving formations must be cased off to avoid catching the tools and so sometimes losing the hole. This means that several strings of casing must be seated at various depths.

Sometimes in comparatively shallow territory a hole is drilled "wet," that is, water sands are not cased off, and the tools are run in a hole in which the water stands high. Drilling is usually done with a steel cable, as the water offers more resistance to a manila cable. In such cases, when the sides of the hole stand up well, casing is not put in until the hole is finished. The practice of drilling "wet" with cable tools is not adapted to any but hard rock fields, and then only rarely does the time and expense saved in casing justify the slower drilling in a wet hole.

When the hole caves badly, it is advisable to keep the casing "following down" not far behind the drill. In such a case a smaller hole is drilled and then enlarged by an under-reamer ahead of the casing. Sometimes the formations are soft enough to permit dispensing with the under-reamer, by fitting the casing with a special shoe which reams out its own hole behind the smaller drilling bit. The weight of the casing is frequently sufficient to move it, but at other times a hydraulic jack is used to force it down.

In badly caving or soft formations, such as those in parts of western Canada, where the casing is liable to "freeze," it has been found advisable to use inserted joint or flush-joint casing (Fig. 52). Not only are the joints stronger, but the friction in raising or lowering the heavy strings is less, by eliminating the heavy screw collars which project beyond the pipe in the usual type of casing.

Another system of casing, occasionally used for comparatively shallow wells (up to 500 or 600 feet deep) in soft unconsolidated formations in California, is the "stove-pipe" method. A similar method is used in the Baku fields in Russia. Riveted pipe in short lengths is used, one length telescoping into that ahead, and the string is forced down by hydraulic jacks as the hole is drilled or is washed out by a "mud-scow," or combination bailer and churn drill. This riveted casing is sometimes used as drive pipe in drilling deeper wells with the usual type of casing, in which case it is driven by blows from an attachment to the drill stem.

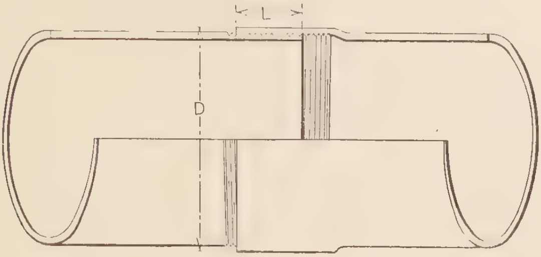

Fig. 52. Typical section of inserted joint casing.

It may be said in conclusion that in drilling in wildcat territory where the number of water and gas sands is unknown and the depth of the oil sand uncertain, and therefore the ultimate depth of the hole cannot be known, one must start with a larger size of casing than that which will probably be used for later wells when the field is developed. Pioneer wells have been drilled in some pools, which failed to discover oil because the hole was so small it could not be carried deep enough to penetrate the sand which was later discovered to be the main oil pay, perhaps only a few feet beyond where the early well stopped drilling.

Wells in the Calgary district in Alberta are started with 18-inch casing. In California even larger casing has been used.

Keeping the log. — One of the greatest needs at present is good logs. Every log should give the top and bottom of every sand which carries gas, oil or water, in addition to giving the distance from the top of the sand to the level where the flow into the well is found. It should also give the top of at least one well-known limestone or coal bed, and this measurement should be taken with a steel line in order that the dip may be properly calculated. Where beds are very lenticular, a more complete record should be kept of changes in the strata, as the correlation of such beds is a difficult matter. When a company is drilling in a new field, and can afford it, a resident geologist should be kept in each active pool to supervise and interpret the logs of all wells as is done by the larger companies in Mexico. In certain fields this might be done by the state geological survey, which might act as a clearing-house for such information, and advise upon such questions as the correlation of certain beds, probable depths, dips in certain directions, and so on. Or this can be done by a competent man whose salary could be paid by a local association of producers.

The elevation of the mouths of the wells should be obtained for the purpose of calculating these dips, and outcrops in the vicinity should be observed and measured so that data may be had as to the dip beyond the edge wells. Without these three sources of information the best results cannot be obtained.

How deep to drill. — Before commencing to drill knowledge should be obtained of the formations which will be passed through. This may be had by one of two ways:

1. By a study of the well logs of the nearest development drilled in the same formations.
2. By a study of the formations at their outcrop, to determine the most promising for oil or gas production.

From this information, the "farewell" sand should be decided upon, and its approximate depth determined by a measurement of the dip of the surface formations along a line from the nearest point of outcrop.

The determination of the depth at which to abandon drilling when oil is not obtained at the expected depth is a matter of very great importance. One can hear many tales in the field of oil reached when drilling was about to be abandoned. In addition to the question of knowing which horizons should be penetrated, there is the important one of knowing when the chances have become hopeless for a given horizon. This is one of the practical reasons for taking steel line measurements on certain key horizons. The depth from the key horizon to the producing sand known in neighboring wells is called the interval. The depth to drill, then, is the sum of the depth from the surface to the key horizon, plus the interval, plus the margin of safety. In some fields, drilling is continued one hundred feet below what is thought to be the bottom of the sand, before abandoning the well.

Even when a well produces oil, if there is no water, one should drill into the underlying shale or limestone a reasonable distance, generally ten feet, but more or less according to local indications; for below a thin shale member there is not infrequently more oil-bearing sand.

Where there is water in the lower part of the sand, which is quite common, care must be employed to stop the drill at the proper point. There are some who habitually stop before there are any indications of water, for fear of reaching it, and others who proceed carelessly and frequently drill too deep. If the pool is young and the pressure high, the driller should stop well above the water, leaving the deepening to the water to a later period. If the pool is old and the pressure greatly reduced, the wisest course, unless the water is known to be encroaching in the pool in question, is to drill until some water sand is obtained, then to fill in for a corresponding short distance before shooting. It is desirable rather than otherwise that some water should be produced, as this is usually a warrant that the full thickness of pay is being utilized, and that some neighbor is not monopolizing its lower portion. Where a well is on a small tract, or on the edge of a pool, so that it will be operated on the beam or on some neighboring power, one may be more conservative as to drilling deep than where a power is available to give the wells as much pumping as is needed.

There are theoretical reasons[1] for believing that there are larger reserves of deep gas than is usually supposed. The practice of discontinuing wells without competent consideration of the chances of success by deeper drilling is a serious loss in the long run. Thus, large areas have been considered "condemned" on account of wells drilled to inadequate depths. Such drilling is a great deterrent to the testing of deeper sands since later tests in the territory cannot have the advantage of possible production in the upper sands, and because the exact depth of the earlier tests may not be known.

The fuel and power supply. — By far the greater part of the wells in the United States are drilled with a boiler and steam engine using natural gas as fuel. Wherever gas can be obtained cheaply, as is the case in most developed fields, it is always used. Where it cannot be used, fuel oil is the next choice. Many wells in the California, Mid-Continent and Mexican fields are drilled with fuel oil used under a boiler, as it is relatively cheap.

The next choice for a fuel is coal, and the preference for it depends upon market conditions, and the grade of coal available, and especially upon transportation conditions in the field. It should always be remembered that in most fields some gas is encountered in the wells on the way down to the oil sand, and this can replace any fuel which has been used up to that time for the rest of the drilling. For drilling wildcat wells at considerable distance from the railroad, as in parts of western Canada and the Mexican fields, wood is frequently used for fuel. Its heating value is not high, and it is relatively expensive compared with other fuels when they can be obtained. Some few wildcats in the Southwest

[1] Johnson, Roswell H., Bull. Amer. Inst. Mining Engineers, Feb., 1915.

have been drilled with brush used as a fuel — principally mesquite and greasewood. This is only done as a last resort.

While the steam engine is by far the preferable form of power for drilling, on account of its flexibility, yet the gasoline internal combustion engine has been adapted by means of clutches to this class of work, as have also internal combustion engines using natural gas. While gasoline engines have been used from time to time, they have never given entire satisfaction, and their use is principally restricted to a few drilling machines and for drilling wildcat wells where transportation of boilers and fuel is difficult. Gasoline engines for drilling can be said to rank with brush under a boiler. In order to increase the flexibility and use of the gasoline engine, an electric dynamo and motor have been added to one type of drilling machine. Since the first cost of the equipment is high, and repairs cannot be so easily made at isolated locations, it will not seriously compete with the use of gas or other fuel under a

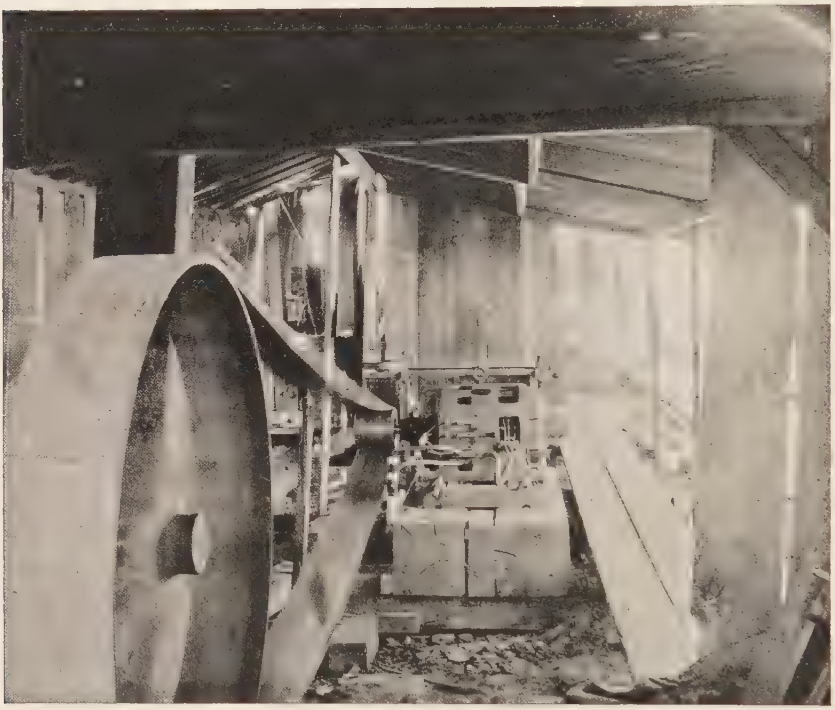

FIG. 53. Westinghouse motor belted for drilling.

boiler, except in unusual instances. However, where cheap electric power is available, as in some of the California pools, motors have been used for drilling purposes, with some success. (Fig. 53.)

In describing the work of churn drilling machines operated by electricity as compared with others operated by steam generated from coal at Bisbee, Arizona, Notman finds that electric drills could be operated from 10 to 25 cents per foot cheaper than steam.[1] However, coal was very expensive, while electric power was furnished by the company's own plant at a price of 3.3 cents per kilowatt-hour. Such conditions are met in but few oil fields.

It is probable that both the internal combustion engine and the electric motor will be found better adapted to use with the rotary system of drilling than with the churn drill. The California fields at the present time are the only ones where electricity has been used to any great extent.

Drilling Contracts. — A contract should invariably be entered into between producer and contractor. The following form is one used for deep drilling in California. In shallower drilling in other fields it is more common to withhold all payment until the hole is completed. The contractor (in such case) guarantees the completion of the hole; any "fishing" expenses thus fall entirely upon the contractor.

THIS AGREEMENT made and entered into this..................day of ....19...., by and between.........................
....a corporation organized and existing under the laws of the State of California, and having its principal place of business at...hereinafter called the OWNER, and COMPANY, a corporation, organized and existing under the laws of the State of California, and having its principal place of business at California, hereinafter called the CONTRACTOR:

WITNESSETH

That the parties hereto, for and in consideration of their mutual covenants hereby agree as follows:

The CONTRACTOR agrees to drill a well for the OWNER to a depth of 3500 feet, in accordance with the specifications hereinafter contained, on that certain piece of land described as...
....

and the OWNER agrees to pay the CONTRACTOR, in Gold Coin of the United States, for said work, the amount, in accordance with the terms, hereinafter prescribed.

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[1] Bull. A. I. M. E., August, 1915.

Drilling Conditions

The CONTRACTOR shall commence the drilling of said well within fifteen days after the execution of this agreement and shall prosecute the work of drilling said well continuously thereafter until said well is fully completed.

The CONTRACTOR shall set a string of 10-inch casing in said well from the surface to a depth to be indicated by the OWNER, not exceeding 2500 feet.

The CONTRACTOR shall also set a string of 8¼-inch casing in said well from the surface to a depth to be indicated by the OWNER, not exceeding 3200 feet.

The CONTRACTOR shall also set a string of 6¼-inch casing in said well from the surface to a depth to be indicated by the OWNER, not exceeding 3500 feet.

The casing shall be set either with or without cement, under the instructions of the OWNER, and after the setting of each string of casing the well shall be bailed sufficiently to ascertain if the water has been shut off, and the well shall then be allowed to stand for 24 hours to test same. If the water has not been shut off after the setting of any string of casing, the CONTRACTOR will then furnish ten days free labor, under the instructions of the OWNER, in a further endeavor to shut off the water.

Guarantees

The CONTRACTOR agrees that all work shall be done in a good and workmanlike manner; that the casing when set shall be open to its full diameter and to its full length so as to permit the passage throughout its entire length, of the next smaller size casing, free and unobstructed.

In the event of the inability of the CONTRACTOR to complete said well in accordance with the terms and conditions hereof, for any cause, the CONTRACTOR shall immediately commence the drilling of a new well at a point to be indicated by the OWNER on the above described property, which new well shall be completed in accordance with all the terms and conditions hereof, provided however, that the CONTRACTOR shall carry such new well to the depth at which the first well is lost, free of any additional cost to the OWNER.

Tools, Materials and Supplies

The OWNER shall furnish a 106-foot derrick with 10-inch I-beam steel crown blocks and complete standard rig, boilers aggregating 120 horse-power connected up, one 12 × 12 drilling engine, sufficient extra lumber for rotary foundations, slush pit and runway, all casing to be set in the well, all cement used and cementing apparatus, water, fuel and lights for continuous operation, and camp buildings for the accommodation of the workmen.

The CONTRACTOR shall furnish all labor, rotary machinery including pumps, swivels, casing lines and blocks, all working and fishing tools, drill pipe and tool joints, and all other materials and supplies not specifically provided to be furnished by the OWNER.

All material and apparatus furnished by the OWNER shall be in good condition and shall be maintained in good condition by and at the expense of the CONTRACTOR and shall be returned to the OWNER at the expiration of the contract in good condition and repair, subject to ordinary wear and tear.

Measurements and Records

The CONTRACTOR shall keep a log of the well, which shall at all times be open to the inspection of the OWNER and the OWNER may at all times inspect the work and take such measurements as he shall desire.

In the event of the OWNER'S failure to check any measurements furnished by the CONTRACTOR, the CONTRACTOR'S measurements shall be deemed conclusive for the purpose of payment.

Liens

The CONTRACTOR agrees to save and hold harmless the OWNER and the land hereinabove described from any and all claims or liens of labor or supplymen arising out of the drilling of said well and against the claims of CONTRACTOR'S employees for injuries received in the course of said work upon said land from any cause.

Payments

The OWNER agrees to pay to the CONTRACTOR the sum of $............. per linear foot for each foot of hole drilled and cased in as follows, to wit:

On the tenth day of each and every month, the OWNER shall pay to the CONTRACTOR, $................per foot for each foot of hole actually drilled during the previous month, and the balance of $................per foot shall be paid by the OWNER to the CONTRACTOR ten days after the completion of said well in accordance with the terms and conditions hereof.

Breach

Upon the failure of either party to fully keep and perform each and all of the terms of this agreement, then the agreement may at once be terminated at the option of the party not in default.

If the defaulting party be the OWNER, then all work completed shall be forthwith paid for to the CONTRACTOR at the full contract price.

If the defaulting party be the CONTRACTOR, then all rights to moneys due under this contract shall be forfeited.

Any breach of this contract by the OWNER requiring the CONTRACTOR to shut down for more than 24 consecutive hours shall entitle the CONTRACTOR to $60.00 per day during the time shut down in excess of 24 hours.

Delays occasioned by strikes or the elements or other causes beyond the control of either party shall not be deemed a breach of this contract.

Arbitration

Any dispute or controversy arising out of this agreement shall be referred to three arbitrators, one to be selected by each of the parties hereto and the two so selected to appoint a third. A decision by the majority of such arbitrators shall be binding upon both parties.

Time is of the essence of this agreement and this agreement runs in favor of and is binding upon the successors and assigns of each of the parties hereto.

IN WITNESS WHEREOF, the parties hereto have caused their respective corporate names and seals to be hereunto affixed by their officers first thereunto duly authorized by resolution of their respective Boards of Directors, the day and year first hereinabove written.

....

By..................................

By..................................

..........................COMPANY

By..................................
President

By..................................
Secretary

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[1] From appendix to the catalog of the Lucey Mfg. Corporation.

CHAPTER XIII

"BRINGING IN A WELL"

The value of having a previous conception of the formations to be entered. — In order to avoid some of the many uncertainties of drilling in new territory, it is essential to have the fullest possible knowledge of the formations to be drilled — the approximate depths to the principal sands, which sands if any carry large amounts of water, and which are the most promising for oil and gas development. These are all geological questions, and must be answered by a study not only of the results of all near-by drilling but also of the prevailing dip of the formations, and the character of such formations at their outcrop. One is then in a position to judge intelligently as to the following points:

1. The approximate number and length of strings of casing which will be needed.
2. The size of hole with which it is necessary to start the well in order to finish with a desired size at the depth of the pay sand.
3. The approximate depths to different promising horizons.
4. At what depth precautions must be taken against blow-outs, so that the well may be shut in without delay when the sand is struck.
5. If drilling with a rotary, where to look for the pay formations, so that the hole will not be drilled past them without recognition.

Precautions where great pressure is expected. — In the past there has been a tendency, when drilling into a gas sand or oil sand under heavy pressure, to take the chance of being able to control the well after drilling in by screwing a gate valve on top of the casing or placing the cap into the top of the casing head. Where high pressures are expected this is foolhardy, and a control casing head should be put in place prior to drilling in.

When from failure to take proper precautions a well goes "wild," a number of contrivances have been successfully used for bringing it under control. One of the best of these is the Mortenson well capper described by Arnold and Garfias,[1] which consists essentially of a long heavy split sleeve or collar attached to a heavy gate valve. The two halves of this sleeve are bolted to the casing below the mouth, the length of the sleeve allowing work to be done in the cellar of the well and protected from the flame if the well has caught fire.

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[1] U. S. Bureau of Mines, Technical Paper 42, pp. 8–10.

A more recent device is the control casing head, invented by A. G. Heggem,[1] which combines the advantages of a gate valve and casing head.

"It is similar in general appearance and size to the common type of casing head in general use. It can be placed above or below the derrick floor, at the will of the operator, and is arranged to receive the standard fittings commonly used with casing heads. The top opening is threaded to receive a drilling nipple or other top connections usually employed in gas wells.

"The interior of the head is bored out to a true cylindrical form into which is closely fitted the plug or valve (Fig. 56). This valve is open at one end to provide a lateral passage for the oil or gas; the other end is reduced in diameter to form a stem, which extends through a suitable stuffing box, and by which the valve may be operated. On the stem side of the valve a flat surface, or flange, fits closely against the base of the stuffing box, making a tight joint, thereby to a large degree relieving the stuffing box of duty in preventing leakage. The extending stem is hexagonal in form to accommodate a wrench, but a transverse hole through it provides a more convenient means of operating by use of a bar of iron, such as a bolt or piece of 1-inch pipe.

"To provide for the convenient operation of the valve at a distance, when the casing head is below the floor or is otherwise not readily accessible, the end of the stem is bored out and threaded to take an extension of standard 2-inch pipe.

"The back of the valve is broad enough to close completely either top or bottom opening in the body, and provide sufficient lap to prevent leaking.

"On each side of the back of the valve is a groove, or notch, of sufficient size to encompass the drilling line, sand line or torpedo line. By this provision the valve, when closed, while completely shutting in any flow, does not injure the line.

"By means of the end opening, as well as by recessing the back of the valve, the pressures within the casing head are to a large degree counterbalanced, making the operation of the valve easy."

During drilling this cylinder is turned so that the cable has an uninterrupted passage, the cut-away part being large enough to allow the passage of the tools or bailer. When it is desired to close in the well, after the tools are removed, the revolving cylindrical member is turned so that the solid side comes opposite the upper opening of the T. This diverts the gas or oil through the end of the cylinder into the lead line which has been screwed to the lateral opening of the T. The opposite end is closed by a stuffing box through which the wrench socket protrudes for operating. (Figs. 54 and 55.) When the well is drilling through gassy formations, or is spraying oil, or is about to drill into the sand, a notch in the edge of the moving part allows the control head to be closed except for this small opening. As a control head

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[1] Heggen, A. G., "The Control of Petroleum and Natural Gas Wells," Bull. A. I. M. E., Feb., 1916.

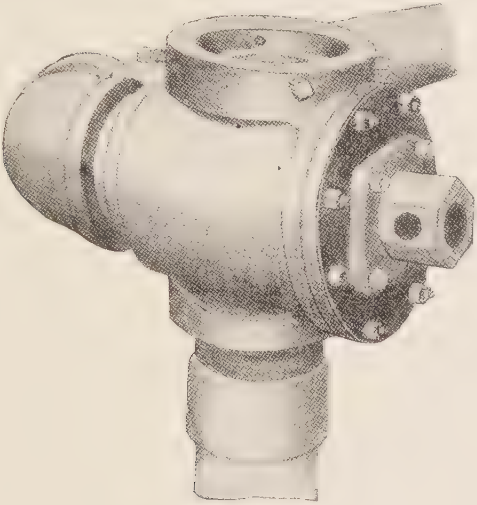

FIG. 54. The control casing head.

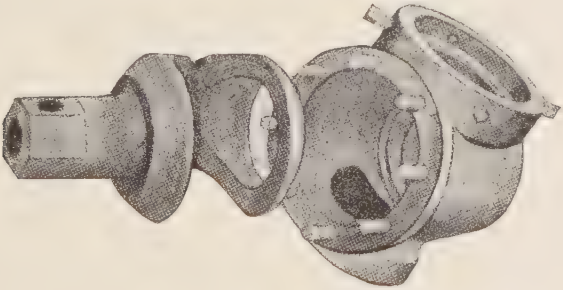

FIG. 55. Control casing head showing plug and valve body.

with a notch of such size as to close around a steel cable also roughly fits the sand line, there is no difficulty from this score, but where they are desired for use with a manila drilling cable, the notch must be correspondingly larger and the control head must be so ordered from the makers. This device may be used in connection with a braden head. It was first successfully used in the Cushing pool in Oklahoma, and its simplicity and effectiveness are causing it to be installed elsewhere.

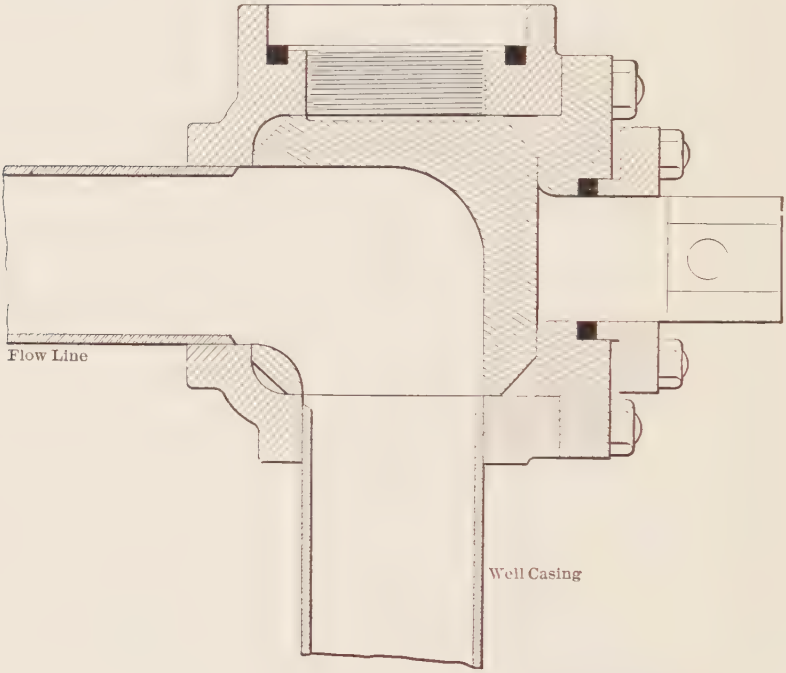

Fig. 56. Vertical section of control casing head, closed.

Where there is danger of the oil or gas blowing up around the casing, thus loosening it and destroying the well, it is well to have the casing bolted down to a concrete anchor, or to a number of wooden "dead men," and then to cement the well outside of the casing as far as possible from above.

Messrs. Heggem and Pollard[1] of the United States Bureau of Mines have also adapted a method, already used in rotary drilling, for holes

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[1] Heggem and Pollard, U. S. Bureau of Mines, Technical Paper, Nos. 66 and 68.

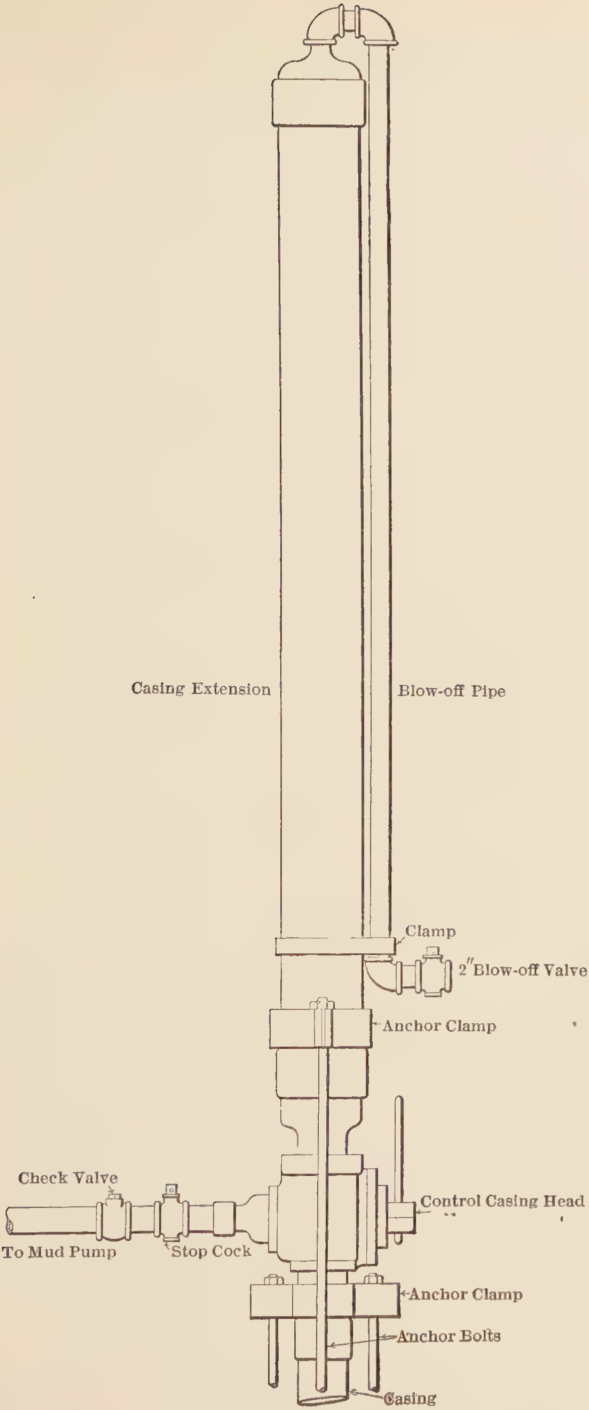

FIG. 57. Application of the control casing head to the method of shutting off gas or water with mud.

drilled by the cable system, a method of "mudding up" the sand face to prevent blow-outs (Fig. 57). This has been very successful in a number of bad cases, shutting off the gas and allowing drilling to proceed. Other wells may later be drilled to this shallow horizon, if desired.

A notorious example of a wild well[1] is that about 2 miles southeast of the town of Oil City, Louisiana, in the Caddo field. This well got beyond control about May 12, 1908, and after blowing a crater in the ground about 40 feet deep, in spite of all efforts to control it by the "lubricator" method of mudding up the sand with heavy mud, it was allowed to blow until the summer of 1913, when it was closed by J. W. Smith for the Louisiana Conservation Commission. This was finally done by drilling a "relief" well at a distance of 125 feet from the old well, and pumping water under pressure into the gas bearing formation, until the gas was forced back into the formation and away from the locality. The old well stopped flowing on the tenth day after the introduction of the water, although pumping continued for three more days.

Day describes the device which was used to close in the famous Potrero del Llano well No. 4, in the Mexican fields. The well was flowing through 8-inch casing at the rate of over 100,000 barrels per day. A heavy clamp was placed just below the collar of the casing, to which was hinged an 8-inch T by means of rods, the upper ends of which were threaded and fitted with adjusting nuts. This T was fitted with two gate valves, and on the lower end had a swage bell nipple from 10 to 8 inches. By means of guys this nipple was brought from a horizontal to a vertical position directly over the top of the 8-inch casing. Then by means of the adjusting nuts on the upper ends of the rods supporting the nipple and gate valve, the nipple was forced down over the casing. A lead line was attached to the lateral opening of the T, so that when the gate valve on the vertical opening was closed, the oil was forced into the lead line, and the well was under control.

Preparation. — As has already been shown, any considerable flows of gas or water, encountered while drilling in the formations above the pay sand, are usually cased off. Gas escaping from the well-head while drilling is going on not only increases the fire risk but often offers sufficient pressure to delay the work. Water coming into the hole in any quantity not only slows up the drill, but is liable to flood the oil sand when the well is drilled in, and thus prevent its being recognized. When the well is completed, it is very important that all water from upper strata should be shut off from the pay sand, to prevent flooding.

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[1] Keen, C. D., Bull. A. I. M. E., Feb., 1914.

The practice of packing, when drilling in the hard rock fields, differs from that in fields where the formations are unconsolidated and where the rotary drill is largely used.

In the cable tool fields such as the Eastern and Mid-Continent fields of the United States, when it is desired to set a string of casing so that all water from the upper formations will be shut off, a harder stratum below the water sand but above the pay sand is chosen and the bottom of the hole is slightly tapered. The end of the casing, sometimes fitted with a special shoe, is then carefully driven into this taper until a tight fit is effected. Then drilling is continued with a smaller bit. This method of packing the bottom of the casing is not always effective and where careful work is desired can be considered only temporary. However, in compact formations it is usually sufficient for the upper strings of casing, while the last string above the pay sand is packed with a special packer. The packer of the usual type consists of a steel cylinder of the same size as the casing or tubing fitting into a taper sleeve. Pressure applied from above after the casing or tubing is landed shoves the tapering portion into a rubber sleeve, which is expanded against the side of the hole and forms a tight joint. The casing is sometimes withdrawn in gas wells and the tubing packed above the sand as described.

Packers may be screwed to the bottom of the last joint of casing or tubing, or may be inserted between joints, depending upon the formations and the location of the water or gas sands which are to be packed off, and also upon various conditions which may make it desirable to carry the casing or tubing for some distance below the packer.

In drilling with a rotary in soft formations, it is usually possible to mud up the side of the hole sufficiently while drilling, to keep back strong flows of gas or water. In fact, the heavy column of water carried in the hole creates pressure enough while drilling to prevent trouble from such sources, except in the case of very high pressures and accidents. Casing is almost always set just above the pay formation, and as the packer used in the hard rock fields would frequently not hold in these softer strata, the end of the casing is cemented to the sides of the hole. This usually serves to shut off all water coming in from the upper formations, and to keep the oil or gas from the main pay from escaping to the surface on the outside of the casing, and also to act as a seat for the casing. Casing is cemented in this way in all soft rock fields, regardless of the method used in drilling. Even in Mexico, where the pay formation is sometimes massive limestone, the casing is cemented, because of the leakage through fractures, and the danger of the oil escaping around the outside of the hole to the surface.

Judging the quality of the sand. — The attempt is often made to determine whether the sand in the drillings from a well comes from an oil sand or a water sand, by its "feel" in the hand or between the fingers, by rubbing it with the tongue against the roof of the mouth or by microscopic examination. It is obvious that if the sand could be brought to the surface in the same condition as it exists when first struck by the drill, without being churned and water-washed, it would be quite easy to determine whether or not it contained oil or water. However, unless small masses of the sandstone can be obtained such tests as those mentioned can only show (1) the general porosity of the sand, (2) the presence or absence of cement between the grains, (3) their uniformity in size or lack of it, (4) whether grains are rounded or angular, and (5) whether or not the sand is obviously stained with oil.

If it is a tight, hard sand, with considerable cement between the grains, its lack of porosity precludes the possibility of its containing or at any rate of giving up oil in any commercial quantity. However, a very porous sand, with little or no cement or fine clay, whose grains are more or less uniform in size — and they may be sharp or rounded — may contain water or oil or both. The mere physical differences in the shape and size and color of the grains, indicating that the sand may be water- or wind-worn or composed of minerals other than white quartz, have little to do with its oil or water content. The fact that æolian sands composed of wind-worn grains are the best containers of oil in the Baku fields in Russia[1] cannot be considered as evidence as to their relative desirability in California, for instance, unless their greater porosity is a factor. Many of the æolian sand-bodies in this country carry a great deal of water and very seldom any oil or gas, such as the St. Peter's sandstone of our Middle West. Wells producing oil from such sands in fields where they are petroleum-bearing may do so very prolifically, because of the greater freedom with which such a sand flows and is expelled from the well with the oil.

Again, the fact that a sand with certain physical characteristics is a water sand in one locality is in itself no evidence that it may not carry oil at another point. Not only does the porosity and character of a sand-body change within short distances, but structural conditions, the character of the surrounding formations and the extent of the outcrop of the sand-body, not the form of the sand grain, are the determining factors in the accumulation of oil or water in a sand. As Paine and Stroud state, "Sands are sands, and the only oil sand is a sand containing oil and the only water sand is one holding water."

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[1] Thompson, A. Beeby, "Oil Fields of Russia," p. 67.

Moreover, the drillings from even a good oil-bearing sand may become so churned and washed as to show no trace of the oil, if the grains are all free. A good test in such a case is to grind up the sand so as to break apart adherent grains, and then wash it with ether, thus extracting any possible oil content. The ether is then evaporated, leaving any oil which may have been dissolved. A very small quantity of oil may be found in this way.

Breaks and shells. — The majority of oil sands are not homogeneous throughout their entire extent. Frequently, and particularly near its edges, a sand-body splits into two or more separate "pays." The separating material is likely to be either shale, "tight" shaly sand, or "slate," and is often spoken of by drillers as a "break." A shell is a thin hard stratum between softer strata. The term is rather loosely used, as the bed may be either limy or sandy.

Because such "breaks" occur in many oil sands, drilling should not be discontinued until well into the formation below the bottom of the last sand. However, in some cases the lower "split" is water-bearing, and if this has been determined definitely to be the general condition for the locality, drilling should be stopped before penetrating such a "break."

Controlling water. — Practically, so far as the oil man is concerned, an oil-bearing rock before being drilled may be considered a "sealed reservoir," but as oil and gas are extracted from it and the pressure is thus reduced, there is a movement inward until the pressure is equalized. This replacement may be made by the entrance of gas, oil or water; but in most fields this replacing agent is salt water from surrounding beds or fresh water either from the surface or from an overlying formation through badly packed or carelessly plugged wells.

Carrl[1] says in this connection:

> The flooding of an oil district is generally viewed as a great calamity, yet it may be questioned whether a larger amount of oil cannot be drawn from the rocks in that way than in any other; for it is certain that all the oil cannot be drawn from the reservoir without the admission of something to take its place.

This something may be gas or water from the surrounding rocks, air entering through older wells or gas which was dissolved in the oil when it was at higher pressure.

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[1] Carrl, J. F., Pa. Geol. Survey, Vol. III, p. 263.

Encroachment of salt water under high pressure. — Encroachment of salt water may take place relatively quickly under the following conditions. Presumably there is another gas pay elsewhere in the reservoir. As the gas and oil are extracted from the pay that is being developed, the pressure is relieved in the distant gas pay. Naturally, the volume of the gas in the latter expands, thus forcing water into the developed pay. If the water is in greater quantity than the oil, occasionally it floods the well entirely in a short time. The oil is thus lost beyond recovery by this well, and the well continues to produce nothing but large volumes of water.

In pools like the Bird Creek pool and certain other northern Oklahoma pools, the initial wells were abandoned in some parts of the district, whereas, after the gas pressure had been diminished as a result of drilling other wells, it would have been possible to have pumped oil from the top of the sand without being troubled by water, because the water would then have been under less pressure.

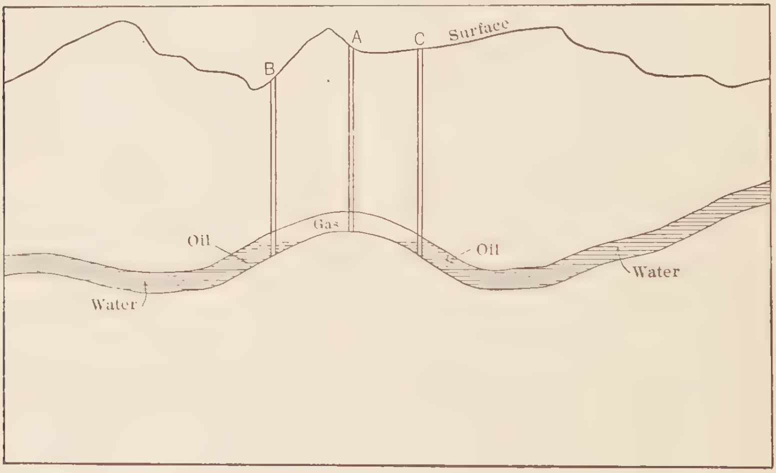

Fig. 58. Showing how encroachment of water drives oil up the dip.

True encroachment to restore equilibrium may occur in a field where there is a strong hydrostatic head counterbalanced by the gas pressure existing in an oil pool, or by a corresponding head of oil, as shown in Fig. 58. As the gas is drained through well *A*, the water advances until wells *B* and *C* are flooded, and the pool fails from its outer edges inward until possibly well *A* produces a little oil along with some water, and in its turn is finally flooded.

By studying the direction of flow of encroaching water, certain wells can sometimes be reserved to be pumped for water alone, thus protecting the others of the group or pool from encroachment. Where a few large operators control production in a certain pool, coöperation in the study of such conditions and concerted action may result in a larger recovery of the oil in the pool than would be possible by any other means. When many small operators are drawing from a pool, water encroachment is seldom made an ally, it is rather an enemy.

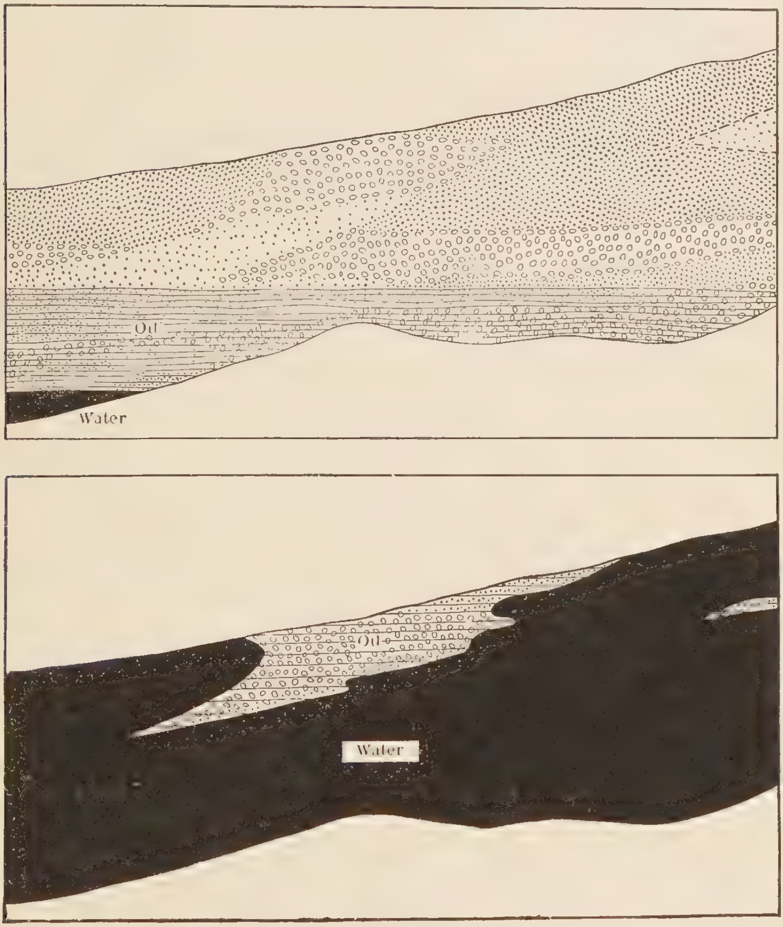

Fig. 59. Effect of water encroachment as influenced by selective segregation of the residual oil in the more porous parts of a sand-body.

As a result of the encroachment of water, part of the oil is crowded up to the roof of the porous formation, and part advances ahead of the water, changing the shape and position of the pool. The oil, crowded into the roof of the formation or caught in "crowns" or irregularities, causes some water wells to continue to produce a little oil with the water, even though all the surrounding wells produce only water. This condition is illustrated in Fig. 59, which shows a pocket of oil retained by a porous lens in the sand after the encroachment of water.

Decrease of production due to flooding by non-encroaching salt water. — The occurrence of water in the lower part of the same porous formation in which the oil is encountered is frequent in pools where the rocks lie almost level. Where such a condition exists, care is usually exercised to stop drilling just short of the water. However, an uneven formation may make it impossible to judge with certainty when to stop drilling. Possibly cleaning or shooting a well may cause it to break through into the water below, or an influx of fresh water from the surface or from an overlying formation may raise the water level above that originally existing in the oil sand. In such cases oil and water are pumped together and in many cases the total amount of water decreases in the course of time. Pumping the water with the oil is an aid to the recovery of oil, the water tending to "flow" the oil toward the well.

Decrease of production due to flooding by fresh water. — Owing to deterioration of packers, to lack of care in plugging abandoned wells, and to accidents in drilling and casing, water is admitted to many oil-bearing formations from the surface or from an overlying water-bearing stratum. Depending upon conditions, this admission of water may have any one of several results.

If the quantity of water is large and the thickness of the porous formation is small, the water may force the oil back so far that it can not be recovered from the well affected. The outflow of water may, however, benefit other wells in the vicinity, and, the field being considered as a whole, the water, by replacing some of the oil, may aid in its more complete extraction. The pressure exerted by the column of water in a deep well is great, especially if the volume of water entering the well is sufficient to keep the column constant.

The flooding by fresh water may account for the phenomenal production in fields where the recovery of petroleum from a sand rock has been relatively much higher than in other districts producing oil from a formation of equal thickness and porosity.

In this connection may be mentioned the danger of drilling wells off shore along large bodies of water, as has been done in the Selkirk gas field in Ontario, along the California coast, and in the Tumbez oil field in Peru for, even though the casing is perfect, there is always danger of storms, collisions, etc. The uninterrupted admission of water into the sand results in the flooding of an entire district.

Although in drilling wells by the old wet method the heavy column of water prevented the early discovery of some oil-bearing strata, nevertheless the gas was conserved and later aided in the expulsion of oil. Some modern wells drilled by the dry method, all water being cased off while drilling is under way, encounter, especially in the Oklahoma fields, a strong flow of gas, which is blown off before the expulsion of oil commences. In any reservoir it is desirable to extract as much oil as possible before the gas. The rock pressure of the pool is thus conserved for the continued expulsion of oil, thus increasing the ultimate production of the district. The recklessness of wasting or even of using the gas first is one of the extravagant practices to which little attention has been paid until now, when the fields are on the point of exhaustion.

Drilling deeper. — This is an extremely important consideration, second only in importance to the selection of the location. With depth, as in the case of locations, geological knowledge and skill are necessary. Quite commonly the tradition is established in a field that it does not pay to drill below a certain "farewell sand." In some instances this decision has been a wise one, but all too frequently it has been the result of ignorance of the formations below, and has resulted in the premature abandoning of thousands of wells. Before any test is drilled, the producer should investigate the formations he is likely to meet, so as to have some idea of the depth. This advance knowledge is also useful to him in drawing up the drilling contract, and in deciding on the method of drilling and the size of the hole. A good illustration of the losses occasioned by loose work in this matter is that of the Cherokee Nation, where most of the early wells were stopped at the Bartlesville sand. Whereas, only 150 feet deeper, more or less, depending upon the location, there is another sand distinctly worth while, and to which new tests now extend, and to which old wells, about to be abandoned, are being deepened. Chautauqua and some neighboring counties in Kansas have been drilled extensively to the Peru sand only, and must now be prospected again for the formations beneath which now seem well worth while. Another illustration is offered in the region from Owasso to the Arkansas River in Oklahoma, where it is quite probable that some producers have stopped wells at the Pitkin limestone, mistaking it for the Boone limestone (Mississippi lime), which is not very much deeper, and is yet distinctly worth drilling to. The Bridgeport, Illinois, pool is another instance where the early unsuccessful tests were almost all discontinued at too shallow a depth, many of them causing the surrender of leases that have since become productive. The most frequent cause of too shallow drilling is the indifference paid to the dip by drillers or producers who have come from older fields, where the dip is so slight as to be ignored by them. A well was unwittingly started at Boulder, Colorado, that could not have reached the producing sand until a depth had been reached much more than twice that of the producing wells of the North Boulder pool. The owner committed suicide. In most fields the geologist can predict the age and general nature of the strata to depths exceeding that feasible for drilling.

Shooting. — Shooting the pay sand with a charge of nitroglycerine is resorted to only in the hard-rock fields. This first shot, after the well is drilled in, and before it is put to producing, has a fourfold effect.

(1) It shatters the pay formation in the vicinity of the hole.

(2) It increases the size of the hole, and thus the surface from which the oil can filter into the hole.

(3) A minor effect is that of forming a considerable cavity which will act as a sort of storage reservoir, and which will not tend to cave in on the tubing, or strain and clog up the working barrel with sand.

(4) The well may have been drilled into a tight area containing little oil in close proximity to a more porous body of sand which contains oil in larger quantities, and the shot may open up a connection with the better reservoir.

CHAPTER XIV

THE MANAGEMENT OF OIL WELLS

Neglect of shallow sands. — We have in the history of many fields a later development of a shallow sand that was passed through by early operators, being considered too insignificant for production, often because gas only was sought at the first. There have been many instances in Oklahoma where oil has oozed slowly from some shallow sand around the casing to the surface. Such a sand has, in nearly every instance, later proved valuable when properly shot. It is remarkable how shooting has made sands productive which at first seemed not worth while.

Method of recovery. — The methods of recovering oil from wells may be classified as follows:

- Natural flow.
- Pumping:
- Individual units.
    - Gas engines.
    - Gasoline engines.
    - Electric motors where current is brought.
- Central power plant with individual motors.
    - Distributing electricity.
    - Distributing steam.
    - Distributing compressed air.
- Central power plant distributing power by shackle lines
- Air lift.
- Agitation.
- Bailers.

The oil from the first wells in a new pool usually flows naturally from the well-head, due to the initial, strong pressure and the saturated condition of the sand. This flow lasts for a variable length of time, depending upon conditions, and the well sometimes flows intermittently, for some time after the continuous discharge has ceased. Or the well may flow intermittently from the beginning, as the gas accumulates, until it has force enough to overcome the weight of the head of oil and sediment which is in the hole.

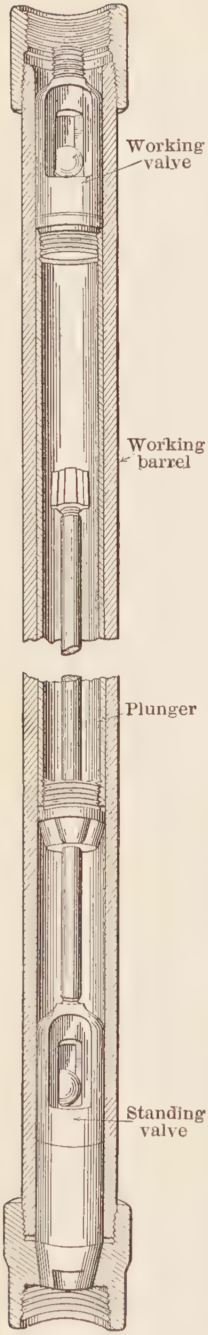

FIG. 60. Typical working-barrel.

In the soft sand fields,[1] such as California, sand and other sediment sometimes run into the hole and form a "bridge," stopping production. To keep the hole free, an agitator string of casing is swung loosely inside the oil string, and churned around whenever the well shows signs of clogging. Wells have thus been kept flowing for some time after they would have ceased normally.

By far the greater number of all oil wells after they have passed the flowing stage are pumped by some type of plunger pump (Fig. 60). The motive power and type of connection vary, however, in many districts, and even in the same field different conditions or ideas may lead to the use of several types on adjoining properties.

Frequently, and especially in the early history of a property or pool, after a well is put to pumping, the engine and walking-beam used for drilling are connected up to the pump. This is nearly always done as a temporary arrangement, but may remain for many months even though it is a very uneconomical method. More commonly, however, a gas engine is installed and is used in connection with the walking-beam on the derrick. On the other hand, the rig may be torn down, and a smaller walking-beam may be connected with the pump, or one of the usual types of pumping-jacks may be installed.

When properties are large enough, and wells not too deep, the most economical way of pumping is by means of a central power plant which is connected with pumping-jacks at the wells by jointed rods or "shackles" attached to an eccentric. The length of the stroke can be regulated by adjustment of the jack, and a well can be disconnected or unhooked when the head has been pumped off. It has been objected that this method is applicable only to fields where the topography is favorable and wells are not too deep; but the tendency is to use this central power more and more as these difficulties are being overcome. It is used extensively throughout the

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[1] Arnold and Garfias, U. S. Bureau of Mines, Tech. Paper 70, and Paine and Stroud, Chapter 6.

Eastern, Mid-Continent, Gulf Coast and California fields. As producing properties tend to be concentrated in the hands of large companies we may look for an increased use of the shackle line in wells of moderate depth, and an extension of its use to deeper and deeper wells.

Production from more than one sand in the same area. — When two oil sands are encountered in the same well, when they are but a short interval apart, the casing is sometimes perforated at the upper pay; or a strainer is put in at the upper pay, while the working barrel is placed near the bottom of the hole and the well produces as from one sand.

This is rarely done when the two pay sands are some distance apart, especially if the gas pressure in the lower sand is higher than in the upper, as is normally the case. This amounts to putting a back pressure on the upper sand, and reduces its production. In such cases, the upper sand may be packed off from the lower, and a string of tubing and a working barrel may be placed at each horizon, and production is carried on independently as from two wells.

Owing to difficulties of construction and maintenance, and especially difficulties in cleaning wells producing from two sands at once, it is generally considered better practice to drill independent wells to tap any shallow pay sand which may be encountered.

Frequency and rate of pumping. — The frequency and rate of pumping an oil well of course depends fundamentally upon the amount of oil coming into the well from the surrounding sand-body. The factors involved are as follows:

(*a*) Rate of flow of oil into the well.

(*b*) Height to which the oil column rises in the well without decrease of the rate of flow.

(*c*) The amount of water (if any) accompanying the oil.

(*d*) Whether the well is pumped by an individual power, or by shackle lines from a central power plant.

(*e*) The frequency with which any one well is pumped may depend upon the average requirements of a group of wells, which govern the pumper's time.

These factors differ with each well, and differ at different periods in the life of a well or pool. They are influenced by changing underground conditions in the pool as a whole, and also by the equipment and management of the well itself as regards casing, tubing, packing, strainers, arrangement of working-barrel, freedom from sand and sediment and the amount of drainage surface in the well cavity.

The rate of flow of oil into the well is in turn governed by such natural conditions as the degree of saturation of the oil sand, its effective porosity, the amount and pressure of the gas present, the area of the surface of the sand exposed in the cavity, and the viscosity of the oil.

In some wells the stroke may be regulated so that pumping proceeds continuously without attention except at times of cleaning or readjusting. In others, the flow into the hole is very slow, so that it must be allowed to "head up" before pumping. Theoretically, pumping should start immediately when the oil has arisen in the hole to the height where its pressure begins to reduce the inflow. It should continue until the level lies at the top of the pay, or in some cases until the oil is exhausted. If the well is producing a paraffin oil, care should be taken not to pump the oil below the top of the pay sand, for fear of drying the face of the sand and causing the deposition of paraffin or other material which clogs the pores and retards the oil flow. Practically, however, a group of wells is usually pumped during a certain time of the day or week, the time being determined by the convenience of the pumper and the average rate of flow into the wells. Where wells are all pumped by shackle lines from a central power, the average length of time of pumping may be entirely wrong for certain units which deserve individual attention. The working-barrel is sometimes arranged so that when the oil level is lowered to a certain point, air is admitted and pumping automatically stops. While this is desirable in certain wells, it is most objectionable in wells in a very porous sand after they have become small. In a change of management or ownership of property, this arrangment may be overlooked, and the whole group of wells may be prematurely abandoned. It generally necessitates pulling the tubing in all the wells and a careful measurement and resetting of the working-barrels, after the wells have reached a certain age.

When considerable water accompanies the oil, it is advantageous to put in a working-barrel and tubing of larger diameter and to use a quicker stroke. Frequently more water is pumped than oil.

When a well is pumped by its own individual power, it is easier to give it more attention than when pumped by shackle-lines from a central power plant. In the high-grade paraffin oil fields this is of more importance than elsewhere, on account of the deposition of wax in the tubing and on the rods and in the working-barrel, if the well is pumped too frequently. However, the advantage of this individual attention is not important enough to offset the lower cost of pumping by a central power. The length of stroke and the rate of pumping can be regulated by the variety and adjustment of the pumping jacks; and a well "on a power" may be pumped a shorter time than others by unhooking it.

In a few fields operators have tried to install a central boiler plant, piping the steam to individual pumps located at the wells. This has not been particularly successful, principally because of the condensation in long steam lines. It has been used most successfully in the Louisiana, Texas and California fields, where the temperature does not cause so much condensation in the steam lines and cylinders as in the northern fields with cold winters.

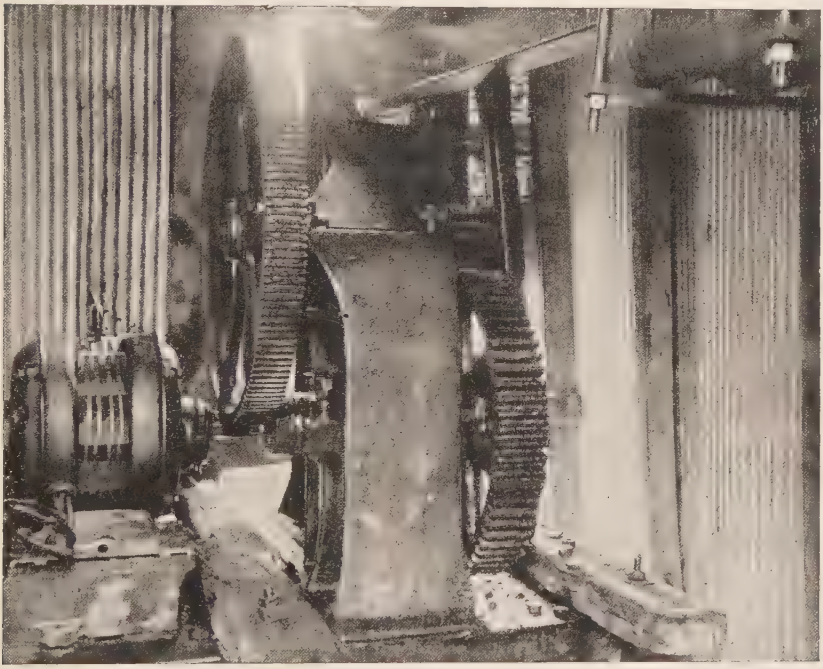

Fig. 61. Westinghouse electric motor connected to pump individual well.

Where wells require much individual attention and a motor of some kind must be kept at each well, the conditions are most favorable for electric[1] motors (Fig. 61). Unfortunately the current consumed is relatively costly.

Compressed air has been used to "flow" wells, but with little success. In this method the pressure is applied in the annular space between the casing and the tubing. This forces the oil down in this space, causing it to rise in the tubing. There are two main objections to this method, as follows:

[1] Oil and Gas Journal, Jan. 13, 1916, p. 61; Electric Journal, Vol. 9, pp. 172–177.

(*a*) It puts a back pressure on the oil sand, and retards production, at the same time increasing the production of neighboring properties.

(*b*) As the wells decline, the oil does not rise high enough in the hole to give a sufficient body of oil which the compressed air can force out. It is thus applicable only to relatively high pressure wells. In small wells the air short-circuits around the bottom of the tubing, and as it rises with the oil, it emulsifies it.

When the fluid rises naturally half up the hole, compressed air has been used successfully in the air-lift method, especially in the California fields.[1] Paine and Stroud state that there is a tendency to form an emulsion with some oils, which is an objection to the method, while with very heavy oils the air forms in large bubbles and blows out without carrying the oil with it. The principal success of the method has been in recovering comparatively light oils accompanied by large quantities of water, such as occur in the Kern River fields. The cost of the method is considerably below any of the other pumping methods of oil extraction in the uncommon circumstances where it is possible to use compressed air for a long period.

Recording the decline. — In general, the yield of a well declines in two stages: (*a*) rapidly while there is high pressure. This period of relatively large production may last from a few weeks to two years, differing with the amount of drilling on surrounding properties, the saturation and the amount and fineness of the porosity of the sand and the pressure. The end of this initial high production and rapid decline, and the beginning of (*b*) a more settled state, may be distinguished as the time of maximum proportionate change in daily yield. In the case represented in Fig. 62, this change to settled production took place at about the 24th month. The change is frequently well marked, particularly in the Mid-Continent fields, but may be indistinguishable in some wells such as those in certain California pools.

In those fields producing from very soft sands, a well sometimes increases in production for several weeks or months, as channels in the sand open up. This is generally accompanied by the expulsion of large quantities of sand with the oil. When high pressures are encountered in the first wells in a pool, wells sometimes "drill themselves in." This means that the oil or gas as it leaves the sand-face actually detaches sand, so that the well is deepened and enlarged.

A careful record of the decline of the wells on an oil property is absolutely necessary to the careful operator or appraiser to complete the valuation of a property. With a knowledge of the characteristic decline curves of surrounding or similar properties, one is able to make an intelligent estimate as to the future course of production of wells on the property under examination. One should, of course, be careful not to place so high a valuation (on a barrel-day ratio) for wells with flush production as for settled production. On the other hand, it is well to be able to judge from such decline curves how many more years of settled production can be looked forward to at the time of sale.

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[1] Arnold and Garfias, B. of M. Tech. Paper 70 and Paine and Stroud, p. 158.

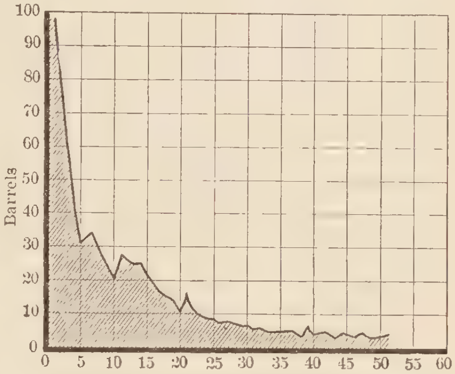

FIG. 62. Decline curve for a typical well in the Bartlesville District, Okla. (Hard sand.)

The production curve of a pool is quite different from that of a single well, for the reason that for the first part of the pool's life new wells and fresh territory are being brought in and developed. The curve thus rises by a series of peaks to a maximum, after which an abrupt decline may be postponed for some time by other new wells or the deepening of old ones. However, the decline curve of a well or of an oil property should always be studied in connection with that of the pool in which it is situated, both as regards production and underground pressures. Other things being equal, that property is worth the most which is situated in a pool whose total production and pressure shows the slowest decline curves. (Figs. 63 and 64.)

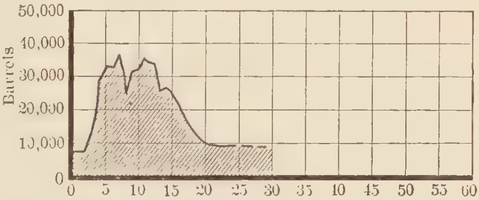

FIG. 63. Decline curve of a typical soft sand well in the Baku Field, Russia. (After Beeby Thompson.)

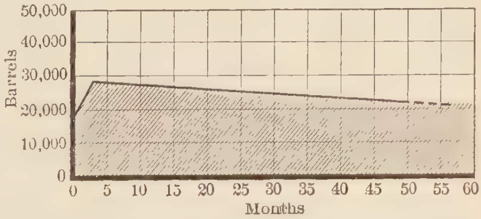

FIG. 64. Generalized decline curve for a well in the Mexican fields. (Fissured formation.)

Pulling and cleaning. — The hole in most cases gradually fills up at the bottom with cavings from the walls and sometimes from the roof of the oil sand. This makes it necessary to pull the tubing and clean the well periodically by removing the accumulated sand by tools and the sand pump. The time of cleaning naturally varies with the condition of each well, but it is done less frequently when the price of oil is low.

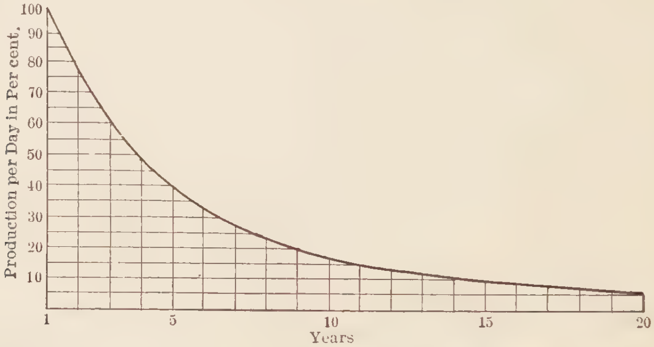

Fig. 65. Curve of decline of production in the Coalinga Field, California. After Lombardi.[1]

There are operators who never clean their wells, others who do so only as a last resort when the well is about to be abandoned, and others who do it periodically. I should say that on an average wells are not cleaned oftener than once in three years. This matter is important, because the practice is so variable for similar wells, and the work is so expensive.

1. *Where water is not found in the sand.*—In case the sand does not carry water, a pocket 10 feet[2] or more deep should be drilled below the sand. Besides the possibility of revealing a second pay the pocket provides a receptacle for loose sand or cavings without affecting the well. The intake of the pump should be opposite the bottom of the pay and have a small air hole in the working barrel near its top at the top of the pay. The first cleaning immediately after the shot should be thorough and should empty the pocket. Such a well, by "sanding" its pump cups, automatically shows when cleaning is needed. As soon as a well in a hard sand is in good shape, the derrick should ordinarily be removed and used elsewhere. Pulling is done with a pulling machine (Fig. 66) and cleaning with a drilling machine. In soft sands, it is better to keep the derrick. The shot should be placed at the bottom of the pay, so that the hole will extend still deeper and, with the pocket, give space for a considerable accumulation of loose sand before the intake is reached. When the well becomes quite small a working-barrel without the air hole should be put in and thus prolong the life of the well.

2. *Where there is non-encroaching water under low pressure in the bottom of the sand.*—If there is water under low pressure in the bottom of the sand, drilling should

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[1] Lombardi, M. E., Valuation of Oil Lands and Properties, Western Eng., Vol. 6, p. 156, 1915.

[2] In the Ontario peninsula, pockets 50 to 100 feet deep are drilled by the leading operators.

be continued until water is evident, and should not be stopped at the depth where water is expected. The pocket should be omitted and the well should be shot to a point only 1 foot above the supposed line between the water and the oil. The first cleaning should be thorough. Efforts should be made to have the well "make" considerable water with the oil, care being taken, of course, not to get so much that pumping through the 3-inch pipe cannot exhaust the water. By taking this water, assurance is had that no pay has been missed, and the current of water flowing to the hole helps to move the oil to the well.

3. *Where there is non-encroaching water under high pressure.* — In case there is non-encroaching water under high pressure, care should be taken to stop wells a little short of the water. They should be drilled deeper to the water when it is desired to clean them. In our opinion, many of our wells, which were deserted because a large flow of water "drowned out" the flow of oil, could have been handled a year or two later when neighboring wells had reduced the pressure.

4. *Where there is encroaching water.* — If there is encroaching water, drilling must stop a little short of the water; hence the shot should not extend to the bottom.

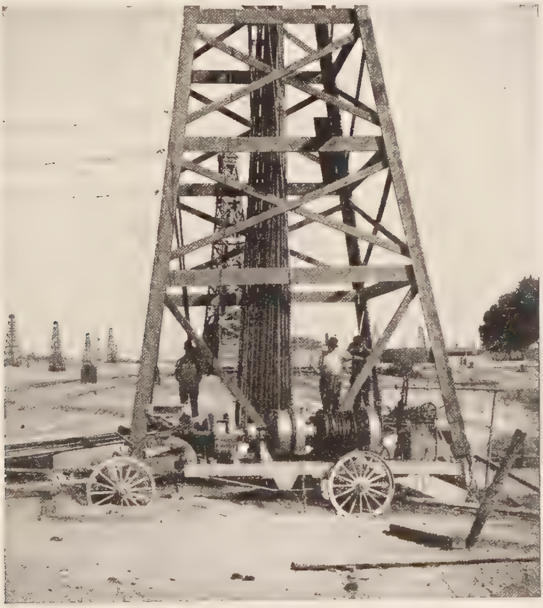

FIG. 66. Portable electric pulling machine (Westinghouse).

In addition to cleaning, in the sense of removing accumulated sand, cavings and mud, there is the need in some cases of also removing an accumulation of paraffin.

1. Hot-billet treatment. This is seldom used at the present time, as in deep wells too much time is consumed in charging the billets. This system also lacks the advantage of keeping the temperature constant at the most favorable point.

2. Gasoline treatment. This is preferable to the hot billet, and is practical where the refinery owns the well and can thus recover the gasoline used.
3. Freshening the hole with a small torpedo. This expedient is not effective when the sand runs into the hole freely. It is probably most useful where water containing certain salts is associated with the oil. It is not used in California or similar soft sand fields.
4. Electric heater. This is the most effective method and has the further advantage of lowering the viscosity of the oil, and so of increasing the production when the oil is very heavy.

Well measurements. — For the purpose of keeping informed upon underground conditions as regards porosity of the sand, general drainage direction, declining pressure, the rapidity of the encroachment of water and its effect on production, as well as for the purpose of determining the average rate of decline for the wells, it is desirable that data be kept upon the production of individual wells.

When the lead lines from all the wells on one property flow into one or two tanks, and new wells are coming in from time to time, it is not only impossible to judge with any accuracy the production of any one well, but it is difficult to estimate the average production of old wells as distinguished from the new. It is obvious that such facts constitute the vital statistics of a producing lease, and deductions made from them must govern the drilling of new wells, their spacing and the location and the rate and time of pumping of individual wells. In the later history of a property, the question arises whether the small amount of oil from a well, at market prices, is worth the cost of operation and maintenance, plus the interest on junk.

In addition to these questions, information as to the individual production of certain wells is needed before the installation of special methods, such as the Smith and Dunn compressed air process. In some pools, the pumping of one well may have a direct effect upon the production of other neighboring wells, and in some instances may make it uneconomical to operate all the wells in the vicinity.

When there are but two or three wells on a lease, even though all flow into one tank, data may be obtained upon their individual daily or weekly production by pumping them intermittently and keeping careful record of the tank gages. This plan may also be followed in the measurement of flowing wells.

The usual method of measuring the production of an individual well is to compare the time required to "pump off" each well or the length of the flow at the tank end of the lead line. Where the wells all discharge into one tank, each by a separate lead line, this method is the most practicable one, although only approximate. More accurate results are obtained by the use of a separate intermediate measuring tank. This extra tank would be fully justified on some leases.

In measuring the oil in a tank when considerable water, sand, foam or cut oil (wax and emulsion) is produced, allowance must be made for the unmerchantable portion which usually collects in the bottom of the tank. This may be as much as 30 per cent of the total volume. Sometimes the oil must be treated by steaming or electricity to separate water and oil in the emulsion, before the oil is marketable.

CHAPTER XV

COMPLETING THE EXTRACTION OF THE OIL

The use of vacuum. — Gas pumps have been used on oil wells since the early years of the petroleum industry, for the purpose of increasing production. The old Triumph pool in Pennsylvania[1] was an historic example, in which a high vacuum is said to have been used, after wells had declined to a small normal production.

In certain fields this practice is profitable at the present time, particularly when the gas is used for the extraction of gasoline. In the paraffin oil fields gas pumping may increase refrigeration at the sand face through volatilization of the lighter hydrocarbons, so as to form wax and thus to increase the resistance to oil expulsion. The method doubtless removes some dissolved gas remaining in the oil, and so by substituting a bubble of gas increases the capacity of the oil to leave the pores. In consideration of these factors, it seems best that the use of vacuum be reserved until the lease will no longer pump oil at a profitable rate without gas pumps.

The few ounces vacuum used on the wells in many of the gas-gasoline plants probably has less effect on the oil production than the higher vacuum.

The introduction of water. — Carrl was one of the first to appreciate the increase in the efficiency of oil extraction by means of water replacement, as he observed it in certain pools. However, water replacement by artificial means (introduction through wells) is severely denounced by Bradford operators. The fault is not with the theory, but in the attempt to concentrate the oil by water flooding with insufficient data as to underground conditions. Clashing interests usually prevent such attempts on a large scale, wells belonging to rival operators sometimes being the first to be flooded.

When water is admitted into a well in large quantities, it tends to flow out in various directions, the greatest flow following the line of least resistance. Owing to differences in the resistance offered by sands of differing porosities and owing to varying amounts of gas in the rock, this movement of the water (and oil) in regions of low homoclinal dip — 15 to 20 feet to the mile — extends up the dip as well as down. The movement is particularly strong in the direction of very porous lenses and toward pumping wells, regardless of the effect of gravitation, the lower levels created by the pumping wells being sufficient to overcome the relatively slight tendency of the fluid to flow down the dip. Thus wells situated above the point of flooding may be affected ahead of the advancing water and abandoned before some of those down the dip are affected. The advancing water, aided by irregularities in the structure and shape of the pool, sometimes surrounds bodies of oil that were originally a part of the pool. Two or three such isolated pools are mentioned by Carrl as having been discovered on the outskirts of the Pithole oil pool after the central part had been flooded.

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[1] Carrl, J. F., Second Geol. Survey of Pa., Vol. III, and Huntley, U. S. Bureau of Mines Tech. Paper 51.

Again, lenticular pebble beds or lenses of unusually porous sand may form pockets in the upper part of an oil sand and may catch quantities of oil, which are retained as the main body of oil advances ahead of the water wave (Fig. 59). These pockets furnish the oil in many wells that, though entirely surrounded by flooded territory, yet continue to produce a little oil along with large quantities of water.

The entering water may shift the whole body of oil from its original position, the extent of such shifting depending on the dip and shape of the pool and its underground structure. The Oil Springs pool in Lambton County, Ontario, is an example. When the pool was first developed it produced from a shallow "pay," an open porous stratum in the "Corniferous" limestone. The wells were all dug and were cased with Scotch casing of large diameter. At the time of the Fenian raid, the field was temporarily abandoned. When operations were later resumed, it was found that the lower part of the casing in a great number of the wells had been corroded away, the wells had caved, and great quantities of fresh water from swamps on the surface had flooded the oil-bearing formation. Deeper drilling developed the present "pay" at a lower depth, and the old wells were abandoned.

In recent years wells drilled through this shallow stratum showed that the amount of water had decreased, and one well struck oil. Other wells were drilled, and an attempt was again made to pump off the water. These operations disclosed the fact that after the spring rains or any large freshet, quantities of fresh water seeping into this porous formation caused the water level to advance up the sides of the anticline upon which the pool is situated, carrying before it a considerable body of oil. By pumping certain wells, located at strategic points, successively as the water and oil advanced or receded, considerable oil was produced.

It was noticed that more oil was obtained upon the recession of the water than upon its advance. As the water advanced, a part of the oil was probably caught and retained in the porous irregularities on the roof of the stratum. As the water receded the contents of these again joined the main body of oil, increasing its quantity. This supposition is supported by the fact that a few wells continue to produce a little oil with the water after the surrounding wells have all been flooded by the advancing water.

One well is reported to have yielded 1300 barrels of oil in three days before failing. As these shallow wells must be worked at great speed to effect a maximum recovery before being again flooded, pumps of large diameter and quick stroke are used.

Owing to the unusual conditions and to the very porous nature of the oil-bearing stratum, the effects of flooding could be observed to unusual advantage in this Oil Springs pool. In most pools the "sand" is less porous, seepage and movement of the water and oil is slower, and local conditions complicate the problem.

The main factors affecting the flooding of an oil-bearing formation may be summarized as follows (adapted from Carrl)[1]:

(*a*) Time of flooding — whether early in the process of operations, while yet a large percentage of oil (and gas) remains unexhausted, or at a later period after the supply has suffered from great depletion.

(*b*) Composition of the formation — whether regular and homogeneous throughout or composed of fine sand interbedded with coarser sand, in places lying near the top and in places near the bottom.

(*c*) Position of the reservoir — whether flat, upon a homocline, upon the crest of an anticline or at the bottom of a syncline.

(*d*) Shape of the area being flooded.

(*e*) Position of the point at which water is admitted in reference to the situation of surrounding wells still pumping oil.

(*f*) Height of the column of water obtaining admittance.

(*g*) Duration of the water supply. It is readily seen that temporary flooding in comparatively fresh territory, from delay in casing new wells or recasing old ones which had been packed with a seed bag in the primitive way, must necessarily be a different affair from flooding caused by a permanent deluge through unplugged and abandoned wells in nearly exhausted territory.

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[1] Carrl, J. F., The geology of the oil regions of Warren, Venango, Clarion, and Butler Counties, Second Geol. Survey, Pennsylvania, Vol. III, p. 265, 1880.

> "In the former case the flood may be checked before much water has accumulated in the rock, and then the oil flow can be reclaimed after a few days of persistent pumping; but in the latter the recovery of oil (except through other wells) is very uncertain, because, being supplied from scattered and obscure sources there is little probability that it can be shut off, although the most thorough and systematic attempts be made to check it."

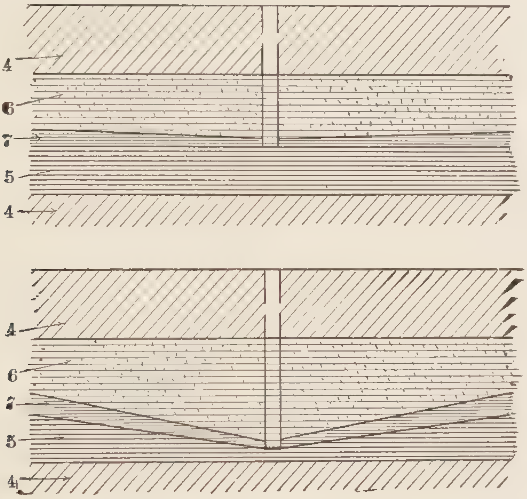

FIG. 67. Effect of drilling into underlying water sand upon the oil-water surface. 4 = shale, 5 = water, 6 = gas, 7 = oil.

In fields where well logs have been kept with sufficient attention to reservoir conditions within the oil sand, and where coöperation between operators is possible, the method of flooding could doubtless be used to advantage. In the event of the development of pools under the Oliver plan, as described on page 112, this method would be particularly valuable.

Local depression of the water table. — A method has been patented[1] by which water is used in moving oil toward the well. This consists in drilling the hole through the oil sand into the water sand (where both occur in the same reservoir and the pressure has been reduced). Then, by pumping rapidly a cone-shaped gradient is set up in the water table around the well, which will aid the movement of the oil inward.

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[1] Johnson, R. H., U. S. Patent No. 1,083,018.

The introduction of air or gas. — Within the past three years Messrs. Smith and Dunn of Marietta, Ohio, have successfully installed compressor plants in connection with various groups of wells in southeastern Ohio. On one property they report an increase from 4½ barrels to 32½ barrels per day, on another from 22 to 70, and on a third from 17 to 32 barrels per day.

The process consists in pumping compressed air or gas into some wells while others are pumped for oil. Gas pumps can be installed on the pumping wells advantageously, and gasoline recovered from the vapors where the gas is rich enough. The process is best adapted to wells producing oil from a sand of even porosity, and not too tight for effective movement. Where there are channels of coarser sand or open joint cracks, the air has a tendency to "short-circuit" along such lines of least resistance, and hence to move little oil. Keeping the bottom of the casing down near the bottom of the "pay" in the pumping wells would prevent a certain amount of this short-circuiting along the top of the sand.

This process has the advantage over the vacuum system alone, in that a positive pressure of much greater strength can be put on the oil body at less cost than any considerable vacuum can be maintained. It furnishes its own replacing material for the oil, which is forced ahead. It also has a much greater radius of effectiveness than the negative force of the few pounds of pressure difference that is made possible by a vacuum. In the vacuum system, the place of the oil must be taken either by water, or by gaseous hydrocarbons volatilized from the oil itself, or by air leaking around the casing. On the other hand, the introduction of air or gas requires that the operator control all wells in the immediate vicinity, otherwise he may be benefiting a neighbor equally with himself. Vacuum pumps may be applied without this consideration. The tendency to "cut" oil in some wells is a disadvantage common to both processes.

Widely disseminated oil. — Although oil and gas are very widely disseminated throughout sedimentary formations of many ages, and are even known to exist in igneous rocks, the accumulations which are of sufficient size and concentration to be of commercial importance at the present time are comparatively rare. Even in such pools, methods of extraction are so inefficient that from 20 to 75 per cent of the original oil content remains in the rock after the wells are abandoned, and there is little hope of improving upon the former figure.

Some of the gas and gasoline lying outside of the pool but contiguous to it can be extracted by the gas pump, and in no other way. It is very gratifying to see this extraction of what has hitherto been beyond reach, and to see the rapid extension of the method.

Our other recourse is the distillation (generally destructive) of extensive beds of shallow oil shales and sands within reach of surface mining. These will be exploited as soon as the price of oil reaches a certain point, which we estimate at $3.00 per barrel. These shales have been worked for many years in Scotland, and to a smaller extent in New Brunswick and Nova Scotia and will be resorted to more and more as our present high-grade oil fields are exhausted.

CHAPTER XVI

THE MANAGEMENT OF GAS WELLS

Recording the decline of pressure with reference to volume produced. — Gas wells differ greatly in their decline, varying with a number of natural and artificial conditions, and they must be handled accordingly. A careful record of these conditions gives a measure by which predictions can be made as to the life of the field, the probable gas yield and the number of wells needed either to develop the leases held or to maintain a given production.

The most important of these measurements is of course the daily volume produced. The initial closed pressure should be taken, and periodically thereafter, as the well is allowed to produce, other closed pressure readings should be taken.

If, then, after the wells have produced 100,000,000 cubic feet of gas the underground pressure has declined 5 pounds, while the original pressure was 600 pounds, it can be assumed roughly that the total production of the pool by the time the pressure is off to 40 pounds would be

$$\frac{(600 - 40)}{5} \times 100{,}000{,}000 = 11{,}200{,}000{,}000 \text{ cubic feet.}$$

If but 5,000,000 cubic feet of gas are turned into the line per day, by the above equation one may assume that the life of the pool will be

$$\frac{11{,}200{,}000{,}000}{5{,}000{,}000} = 2240 \text{ days} = 6.1 \text{ years.}$$

In practice this is not strictly true as the yield decreases with pressure, and is modified by the number of wells drilled in the pool, by the encroachment of salt water, by retardation in tight sand wells, by the size of the reservoir, and sometimes by leakage through the well into an upper low-pressure sand.

The calculation for the whole pool is relatively simple, but since most companies have competitors in the same pool, it becomes necessary to keep careful record of the decline in pressure and volume of each well after the drilling in of a neighboring well. It is then possible to make more reliable estimates on leases.

Sometimes a gas well is permitted to put as much gas into the line

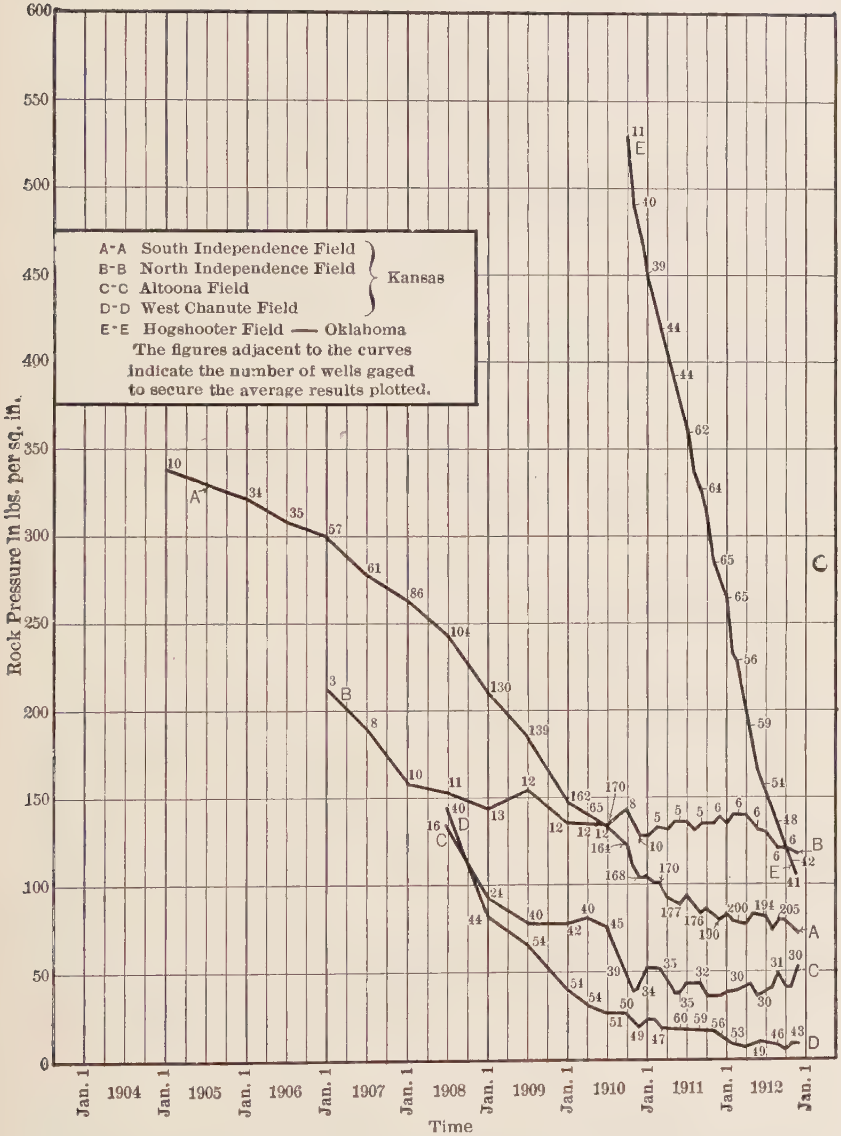

FIG. 68. Decline in pressure of natural gas wells in Kansas and Oklahoma. Courtesy S. S. Wyer.

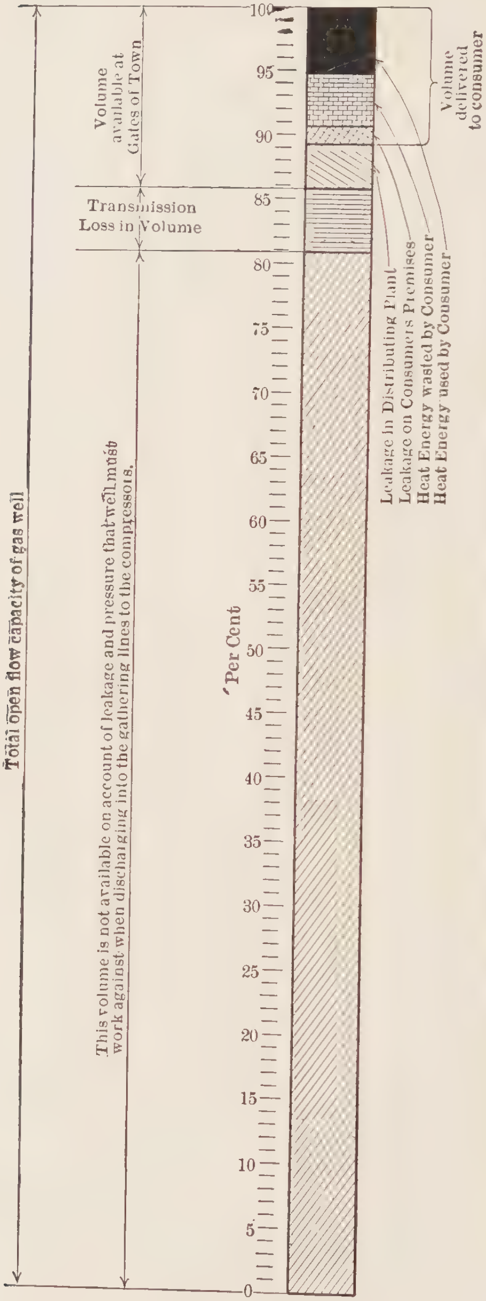

FIG. 69. Proportion of open flow capacity of a gas well available for use. Courtesy S. S. Wyer.

as possible, and when the sand immediately around the hole has been drained, the well is shut in, or allowed to produce less. This gives it a chance to "pick up," that is to say, to give it time for the gas from the periphery of the drainage zone to restore the equilibrium within the drainage radius of the well. This practice is severely condemned, for shortening the life of the well, but it results in the same amount of gas being produced eventually as though the well were only allowed to produce up to a certain proportion of its capacity. It is only where the encroaching water is a menace to a lease, that drawing upon a gas well to its capacity is dangerous. Even in pools with encroaching water, wells that are "up-dip" may open wide without danger.

A rough measure of the yield of a well, which is frequently used, is to take the time necessary for the pressure to rise in the well, after it has been closed in, from zero to its maximum. The "minute pressure," or the increase of pressure after the well has been closed one minute, is taken as a standard. No satisfactory formula or table has been devised to convert this to yield, though they are both clearly correlated.

In some pools water encroaches in certain areas and along certain paths more than in others. These areas are likely to be those in which the porosity or thickness of the sand is greatest, and particularly where an exceptionally porous sand or gravel body communicates directly with the water-saturated zone down-dip. Along such lines one is likely to find abnormally large wells of short life. However, conductive conditions to this premature encroachment of water may be brought about by concentration of wells at a certain point, or by drawing upon certain wells to their full capacity where the sand is already favorable for water encroachment.

Protection from "top water." — The methods[1] of casing off water found above the sand by means of a taper seat for the casing, or by packers, or by cementing if the formations are soft, have already been described in connection with oil wells. In case water increases in the gas sand in a certain pool, and there is reason to believe that it leaks from upper water-bearing strata, a careful record should be kept of the rate of increase in all wells, together with any other data which gives a clue to the particular well through which leakage is taking place.

Where there is a gradual accumulation of water in a gas well, this can sometimes be cleared by "blowing" the well periodically. Wells which produce only through the casing cannot be blown, and the opera-

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[1] Oatman, F. W., "Water Intrusion and Methods of Prevention," Bull. A. I. M. E., Mar., 1914.

NAME OF WELL	Frank White	Wilmot Sperry	Ellen M. Jackson	W. L. Parrot	G. R. George	D. W. Wallace	Elizabeth Kaiser	Charles Carey	W. C. Cooper	W. O. Hawkins
TOWNSHIP	College	Clinton	Milford	Clinton	Clinton	Morgan	Clinton	Liberty	Clinton	Clinton
DATE	Nov. 28	Nov. 21	Nov. 27	Dec. 22	Nov. 20	Dec. 22	Nov. 22	Nov. 26	Dec. 21	Dec. 21
GAGE PRESSURE AT WELL	35 lbs.	17 lbs.	22 lbs.	14 lbs.	20 lbs.	10 lbs.	17 lbs.	15 lbs.	16 lbs.	16 lbs.
GAGE PRESSURE AT COMPRESSOR INTAKE	8 lbs.	4 lbs.	14 lbs.	1 lb.	5 lbs.	1 lb.	4 lbs.	8 lbs.	5 lbs.	5 lbs.
PRESSURE DROP BETWEEN WELL AND COMPRESSOR	27 lbs.	13 lbs.	8 lbs.	13 lbs.	15 lbs.	9 lbs.	13 lbs.	7 lbs.	11 lbs.	11 lbs.
NATURAL OR OPEN FLOW IN 24 HOURS CU. FT.	49 500	45 000	132 000	75 000	70 000	74 000	50 000	49 500	100 000	87 000
ACTUAL FLOW INTO LINE IN 24 HOURS CU. FT.	16 000	24 000	76 800	45 600	43 000	48 000	33 600	33 600	88 000	76 800
PER CENT OF OPEN NATURAL FLOW USED	32	53	58	60	61	64	67	68	88	88

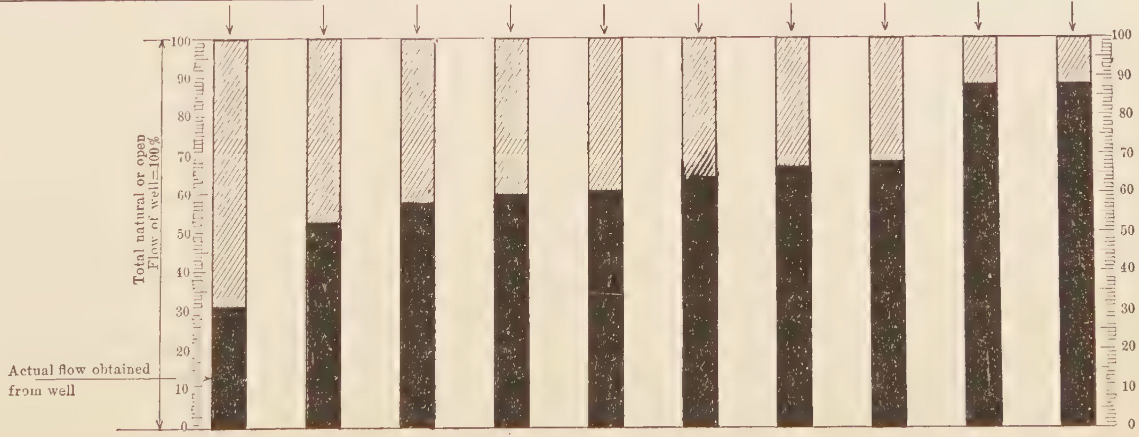

FIG. 70. Natural or open flow and actual line flow from various wells of Ohio Fuel Supply Co. in Knox Co., O., in 1913, discharging into intake lines to Homer Gas Compressing Station. Courtesy S. S. Wyer.

tion is sometimes ineffective even when the well is tubed. In such case, a blowing line of $\frac{3}{4}$-inch pipe is used inside the tubing or casing, which is perforated opposite the gas sand. If the pressure is inadequate even for this small column and there is no "floating sand" in the well, a 1-inch working-barrel may be installed, using the $\frac{3}{4}$-inch tubing as a sucker rod as well as a conductor for the water. The top of the $\frac{3}{4}$-inch tubing should work through a stuffing box on the top of the main tubing with a small walking beam and gearing. A horse can be used for power, or a two to four horse power gas engine.[1] With the blowing method, water can be raised through a $\frac{3}{4}$-inch "siphon" from a depth of 1200 feet with a 75-pound gas pressure, and from a depth of 1500 feet with a pressure of 125 pounds.

Where water occurs in the lower part of the gas reservoir, or is perhaps separated from the gas sand by a thin shell, the early wells in a field often enter it. Or, where the sand is not too hard, the well may "drill itself in" before the gas well is capped so far as to penetrate the water reservoir below. In wells drilled after this condition is known, care is used to stop drilling before the water zone is reached. When it is penetrated, it may be plugged off by the use of a special bottom-hole packer usually made of lead, or it may be cemented.

In the case of encroaching water, wells located at strategic points may

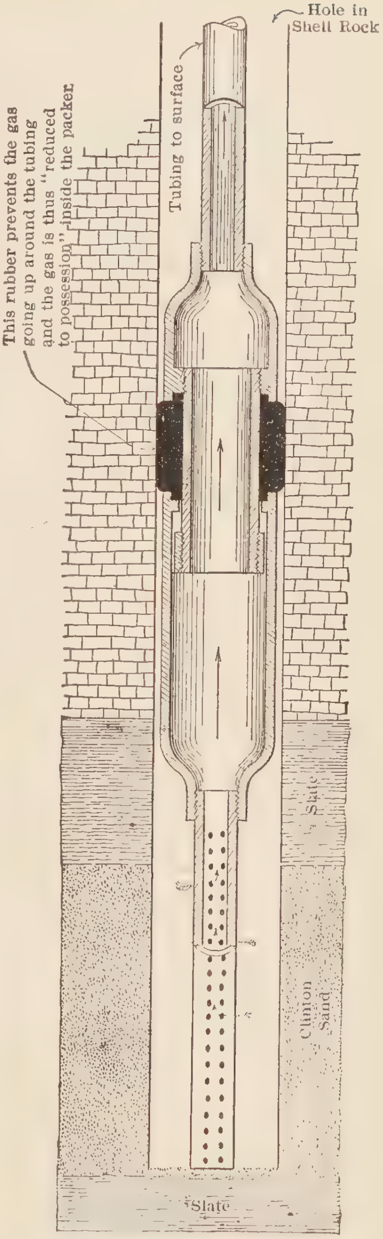
Hole in Shell Rock
Tubing to surface
This rubber prevents the gas going up around the tubing and the gas is thus "reduced to possession" inside the packer
Slate
Clinton Sand
Slate

Fig. 71. Packer at bottom of gas well. Courtesy S. S. Wyer.

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[1] Westcott, H. P., Handbook of Natural Gas, p. 167.

be pumped for water alone, with pumps of large diameter so as to keep the gas reservoir from being prematurely flooded. If the whole pool is owned by one company this does not pay.

In all gas wells, whether dry or not, it is considered the best practice to install a "drip" near the well, to catch any water or condensed well vapors, or any sand or other sediment thrown out by the well. A "drip" of this kind is essentially a section of larger pipe inserted in the lead line, which by suddenly increasing the diameter of the passage and changing its direction of flow causes the gas to drop a part of any load of sediment or condensate it may have been carrying.

Casing-head gas. — Casing-head gas is the term used to describe the gas accompanying the oil in an oil well, which usually contains gasoline vapor. On many properties this gas is used for power, and in some cases is sold off the property merely as gas. The back pressure from such gas lines retards the expulsion of oil, and in some instances in Oklahoma has caused a marked decrease in the production. While possibly the ultimate amount of oil produced from an oil reservoir is the same, in spite of the retardation caused by the back-pressure on this casing-head gas, yet in practice it usually results that such a property loses oil to a neighbor who uses the gas.

If the analysis warrants, it is desirable to have a gasoline extraction plant, for in addition, it lifts this low-pressure gas to such pressure that it can be sold to the gas lines and yet not produce back-pressure on the sand.

Drips, significance or variation with temperature and pressure. Value of records.[1] — A rough indication of the gasoline content of the gas in any well can be gained by observation of the drip under different conditions. A relatively poor gas may show some condensed hydrocarbons in the drip during very cold weather. But if such condensation continues in fair volume during warm weather, it is certain that the gas is one of considerable richness, and valuable for the commercial extraction of gas-gasoline. Records of the amounts of condensate found in gas well drips under varying pressures and temperatures are of value in judging whether there is probably oil in other parts of the same reservoir. They may even serve as a guide to the best direction for prospecting. In the same well the condensate increases with the decrease of pressure.

Paying by calorific value. — The gas in any particular district is usually of a generally uniform composition, particularly that piped for domestic or commercial purposes. Casing-head gas has more heating value than the usual dry gas even after extraction of the gasoline, but is seldom piped to any great distance from the pool. Warren, Pennsylvania, and Sistersville, West Virginia, are supplied with casing-head gas for domestic purposes, however. Commercial natural gas in different localities varies in general between 850 and 1100 B.T.U. in heating value. If certain wells in a district produce poorer gas than the run, the pipe lines can still afford to take it, as the dilution is so great that the average is only slightly affected.

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[1] U. S. Bureau of Mines, Bull. 88.

On the contrary, in southern Kansas some gas is produced containing so much nitrogen that it has a heating value of only 600 B.T.U. Operators owning these wells were recently obliged to disconnect their wells from one pipe line which could not afford a lowering of their gas quality, and to sell to another line which carried a great deal of Oklahoma gas which could stand dilution.

In the case mentioned, the defect in quality was so marked that there was no commercial market for the gas as it was produced, until it could be sold to a pipe line company who could afford to dilute its gas.

On account of the usual local uniformity in the quality of natural gas, it has never been sold on the basis of its relative heating quality, although this may occasionally be desirable. However, when the cost of production and transportation of natural gas has risen to a point where it approaches the cost of artificial gas, this discrimination will be made, so great is the difference in quality. The cost of artificial gas for domestic purposes is also a factor which governs whether or not natural gas is to be piped to certain cities in the future, particularly to those on the Atlantic seaboard. Another factor is the prospect of a sufficiently long-lived supply to repay the investment in the transportation and distribution plant.

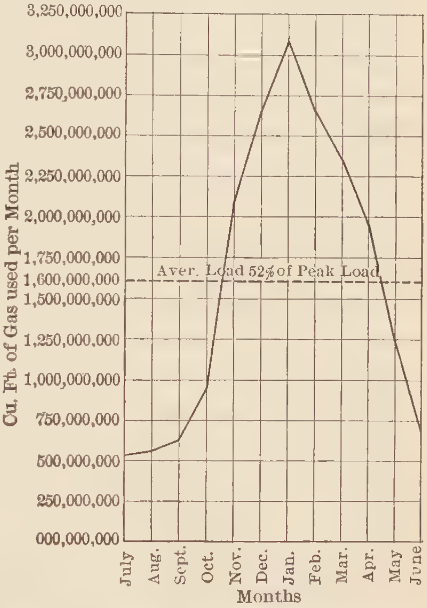

FIG. 72. Monthly domestic load of Natural Gas Co. Courtesy S. S. Wyer.

In the principal natural gas fields, however, the main factors governing the price of natural gas, irrespective of variations in heating value are (1) cost of production, (2) competition, (3) size of market in the immediate vicinity, (4) quantity of gas available and life of wells, and (5) whether prices of artificial gas and other fuels in distant cities offer the prospect of developing markets for the gas elsewhere.

CHAPTER XVII

CONDENSATION OF GASOLINE FROM GAS

The significance of the variation in the amount of condensate found in gas well drips and in the gas traps on oil wells, under varying conditions of temperature and pressure has been discussed in the preceding chapter. Such evidence gives a good clue as to the gasoline content of the gas in such wells. However, as the market conditions in the various fields differ as well as the cost of extraction of the gasoline, this evidence should be supplemented by (1) an analysis, and if this proves favorable, by (2) test runs in a small model field plant. These small test plants[1] are now made in a portable form, so that they can be taken from one property to another. The amount of "wild" gasoline up to 90° B., which can be extracted from casing-head gas at different localities, varies from one to four gallons per 1000 cubic feet of gas, with 350 pounds compression. In practice, commercial plants produce from 1½ to 3 gallons per 1000 cubic feet of gas, and are able to market from 60 to 80 per cent after the loss in weathering and shipping.

Common practice is to use a two-stage compression, the first stage from 25 to 50 pounds, and the second from 120 to 150 pounds per square inch. The gasoline produced is often higher than 88° B. It is then allowed to weather down to this gravity before being shipped to a refinery for blending with low-grade naphtha. Or the blending may be done at the gasoline plant, and the blend weathered later before being sold. The lighter portion ordinarily "weathered off" may be sold under high pressure in special tanks for house illumination, welding, etc., under the name of "gasol."

Choice and location of plant.—Burrell[2] estimates that a single unit plant, consisting of two gas compressors, gas engines, piping, cooling coils, storage tanks, housing, etc., costs about $9000 or $10,000 and can handle at least 500,000 cubic feet of gas daily. The fixed charges vary widely, and include interest on investment, depreciation, plant upkeep, accidents, etc., all of which must be taken into consideration.[3] In the Mid-Continent field it is generally believed that a plant, operating upon a gas which does not yield 2 gallons of marketable gasoline per 1000 feet of gas treated, does not make a profit with gasoline retailing at from 11 cents to 12 cents per gallon. Of course in such fields as those in Alberta, a poorer gas can be worked, as there is a government bounty on mineral oils in Canada, and the market lies at such a distance from the nearest refinery that gas producing but 1 gallon per 1000 cubic feet of gas could probably be worked profitably, with gasoline at 25 cents per gallon or higher in that district.

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[1] U. S. Bureau of Mines, Bull. 42, pp. 91–110.

[2] U. S. Bureau of Mines Technical Paper 57 and Bulletin 88.

[3] Westcott, H. P., Handbook of Casinghead Gas.

The choice of the location for a plant depends upon the following factors:

(1) Analysis of the gas in the pool (gasoline content).

(2) Quantity of gas available.

(3) Probable life of the wells.

(4) Market for gasoline, or distance from refinery where it can be blended, or from which low-grade naphtha can be brought for blending with the "wild" gasoline.

(5) Probable amount of fixed charges, calculated from the cost of plant at that point, and other factors given in the preceding paragraph, an estimate of which should be made from similar plants[1] in other localities.

(6) Range of gasoline prices in the district for the past, and probable future range which can be expected, in consideration of the large annual increase in the number of automobiles (Fig. 146) and the price of crude oil.

(7) Market for the residual gas from the plant, after the extraction of gasoline.

(8) Whether the plant is operated as an adjunct of an oil property which is itself on a self-supporting basis, or whether a royalty must be paid to the well owners, and the amount of this royalty.

(9) Whether after the abandonment of the original wells, the plant can be connected with other properties in the district, or whether the entire cost of the plant must be borne by the wells with which it was originally connected.

In some pools it has been found that the best results are obtained by keeping a vacuum on the wells from which casing-head gas is being used. The degree is a matter for initial experimentation by each plant. Various plants in southwestern Pennsylvania are using from 4 to 28 "points." The vacuum should be gradually increased as results indicate. The determining feature is not the actual yield, but the yield per 1000 feet of gas.

The pressures used in the second, or high stage, are governed by the gravity of the gasoline it is desired to produce. If too high pressure is used, the very light gases are also extracted, and these are in turn easily lost by evaporation in the weathering process. The practice is seldom to use more than 150 pounds pressure in the second stage of the compression, yet this should be a matter of experimentation at each plant where conditions differ from those in other fields. For example, different gases act differently in the quality of the condensate produced, and in one case the gasoline produced may lose relatively little by weathering while by using the same compression on another gas the gasoline will be very "wild" and could not be shipped without exhaustive weathering. Again, there may be a limited local market for very light gasoline for special purposes, in which case the gas-gasoline might be sold at a premium without blending. As soon as the market expands in this country for the very light petroleum distillates which can be used for various purposes in the chemical industries, there will be a tendency to increase the pressures in the gas-gasoline plants in order to recover more of these products.

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[1] Pamphlets, Bessemer Gas Engine Company.

The gas from the same well increases its load of condensible vapors as the pressures decline with time. Moreover the gasoline extracted becomes regularly heavier as the well ages. Casing-head gas which is too lean at high pressure may therefore become suitable later; and gas wells without oil, which generally are too lean at first, may become suitable when the pressure is greatly reduced. Since gas pipe lines have a constantly increasing percentage of their wells with lowered gas pressure and below atmospheric pressure, their gas is in general becoming richer. Fortunately a new process has been developed — absorption in a heavier oil — which makes it feasible to treat great quantities of gas rapidly so that all the gas in a main gas line may be handled. Where there are compressors, this should be done as the gas leaves the compressor. The oil with its absorbed gasoline circulates through a continuous still where the gasoline is driven off and then condensed, and the oil returns to the absorbing apparatus which is very long in order to get good contact between the absorbing oil and the gas. The circulation of the absorbing oil is continuous but the rate is adjusted as is indicated by the amount of gasoline to be removed from the oil.

Absorption apparatus can be installed to handle any desired quantity of gas from a few thousand feet per day up to 20,000,000 feet per day or more, handling the large or small quantity to equally good advantage. Gas yielding one quart per 1000 cubic feet or even less can be treated to advantage by this process, where the quantity of gas is large enough to give an amount of gasoline more than sufficient to pay the cost of maintenance.

This process is especially valuable in lines where rubber couplers are used instead of welded lines, as the resulting gas is "dry" and does not deteriorate the rubber in the couplings.

There are three methods of marketing gas-gasoline at the present time:

(1) Selling to a refinery for blending with low-grade refinery naphtha, in order to make a commercial grade of gasoline.

(2) Buying the low-gravity naphtha for blending at the gasoline plant, which then markets its own gasoline.

(3) Selling the product without blending for special purposes. There is a small but expanding market for the light distillates in the chemical industries.

Royalties. — A decision[1] in the West Virginia Supreme Court is to the effect that when no provision is made in an oil and gas lease for royalty on gas produced incidentally with the oil, there shall be no royalty or rental paid on the well as a gas well. This apparently leaves the status of gasoline condensed from this casing-head gas as yet undetermined, as to whether or not it should pay royalty as crude oil. In practice this matter of royalty on gasoline produced from casing-head gas, and on the use or sale of the residual gas after such condensation, should always be carefully covered in the lease. There is a great variety of provisions[2] in leases with a growing tendency to specify that such gasoline shall pay a royalty, although this may be at a different rate than that on the crude oil produced.

[1] Oil and Gas Journal, Mar. 4 and April 1, 1915.

[2] See p. 99 for a discussion of the gasoline provisions in a lease.

CHAPTER XVIII

THE NATURAL GAS INDUSTRY[1]

Natural gas has been used in the United States since the early part of the last century. However, prior to the beginning of oil production in the sixties, gas as found in water wells had only been used in a few isolated cases for fuel or lighting. In the early drilling for oil, the gas found incidentally was looked upon as a nuisance and was blown off and burned in flambeaux throughout the oil country.

Then, as the value of the gas as a fuel began to be appreciated, it was piped short distances to near-by towns and used for street lighting, and for various industrial plants such as salt works, glass plants, potteries, brick yards and later for the manufacture of lamp black. In fact, once the use of gas became generally appreciated, municipalities seized upon the advantage of its proximity to advertise their towns as sites for plants which depended upon cheap fuel for their operations. To influence such concerns in locating their plants, free gas was guaranteed in some cases for a considerable term of years, and in practically unlimited quantities. This period began in Ohio in 1885 in the vicinity of Findlay, and the principal towns in that part of the state undertook prospecting and drilling operations as a municipal enterprise.

When producers realized that this hope was merely an illusion, and that underground reservoirs once exhausted of their gas content did not recover, the more flagrant forms of waste were discontinued by the more progressive companies. From that time to the present, there has been a progressive tendency toward the use of more efficient burners for both heating and lighting. The sale of gas to both domestic and industrial consumers by meter has also tended toward more efficient methods of use and hence towards conservation.

However, although natural gas has from 50 per cent to 100 per cent higher heating value than artificial gas, yet the latter is sold at an average price of $0.85 per thousand cubic feet, while natural gas commands an average price of but $0.30 per thousand for domestic purposes and much less than this for industrial purposes. Artificial gas does not, of course, compete in the industrial field, on account of its high cost, except in a limited way. At the same time the lower priced natural gas can be used for all purposes for which the artificial gas is employed, and in some cases to better advantage. This very cheapness tends to wasteful methods of use.

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[1] The authors are indebted to Mr. S. S. Wyer, of Columbus, Ohio, for most of the illustrations for this chapter. Bull. A. I. M. E., Feb., 1915.

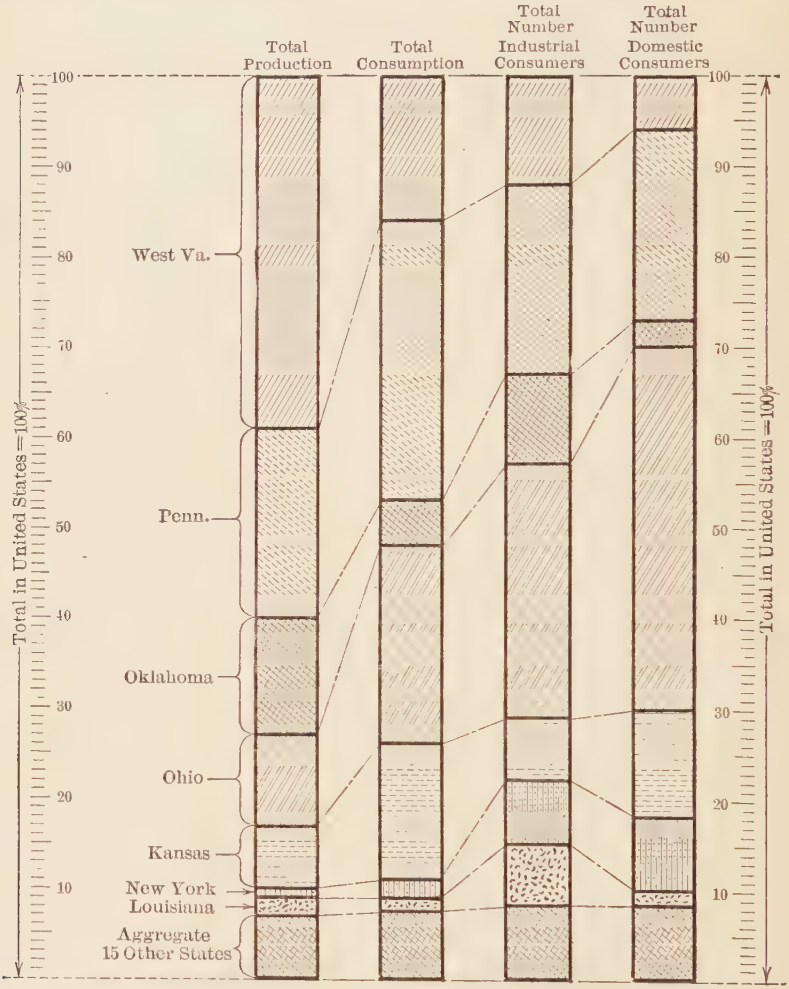

FIG. 73. Interstate relation of production and consumption of natural gas in the United States.

In the early history of such operations, there were many theories as to the origin of oil and gas, some maintaining that gas was still being formed in underground sources, and that wells would recover their production if shut in and allowed to recuperate for a time. This view was apparently supported by the now well-known action of many old gas wells, in partly developed fields, of "picking up" in pressure for a con-

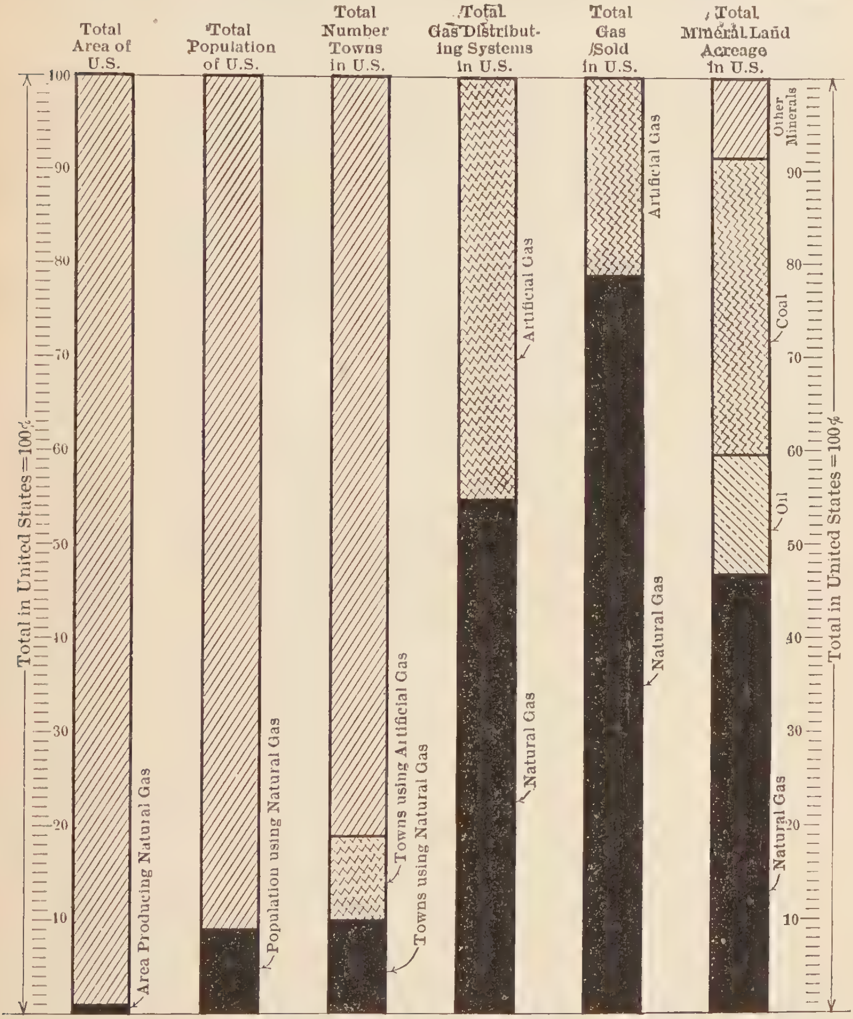

FIG. 74. Relative geographical features of natural gas industry in the United States.

siderable time after being shut in. This is now known to be due to the gradual reëstablishment of equilibrium in the sand, and not to the formation of new gas.

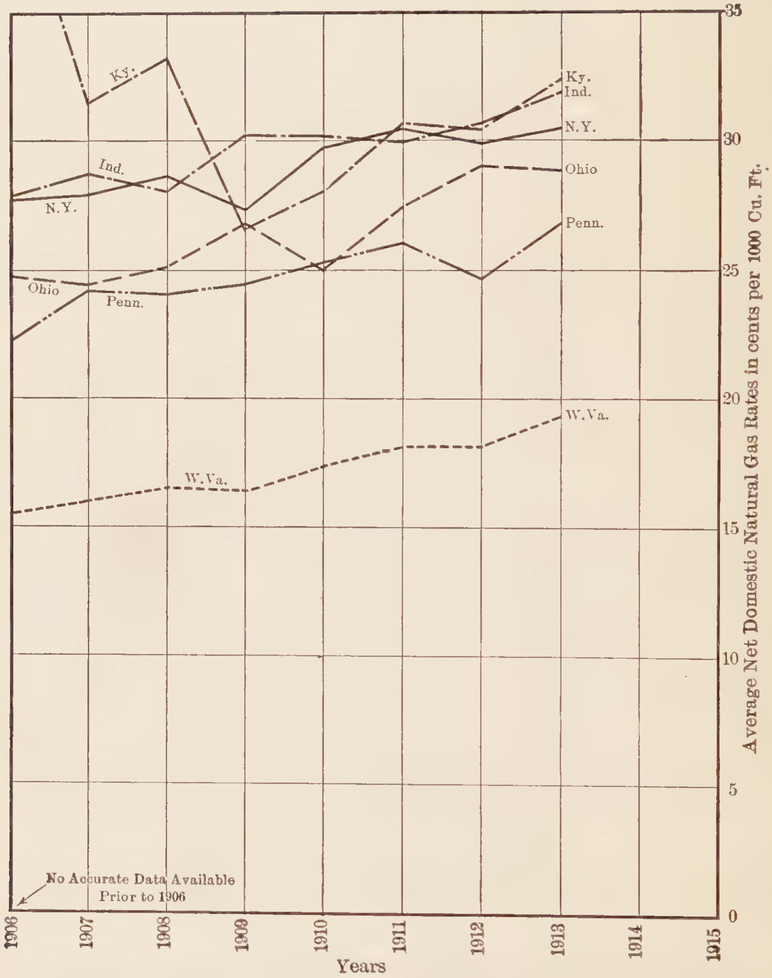

Fig. 75. Average net prices to consumers of natural gas in various states, based on U. S. Geological Survey statistics.

While the prices of all commodities have risen within the past ten years, yet the relative rise in the average price paid by domestic consumers for natural gas has been less than that for foodstuffs and farm products (Fig. 79). In general, it may be said, that the price for natural gas is too low rather than too high. When the regulation of gas rates is under consideration, one should always remember that the greater proportion of low-pressure gas used, the increased amount of deeper drilling, the longer pipe lines, the increased use of compressors, and the necessity of leasing and retaining larger blocks of land to protect producing wells and insure a future supply of gas (Figs. 76, 77 and 86), all

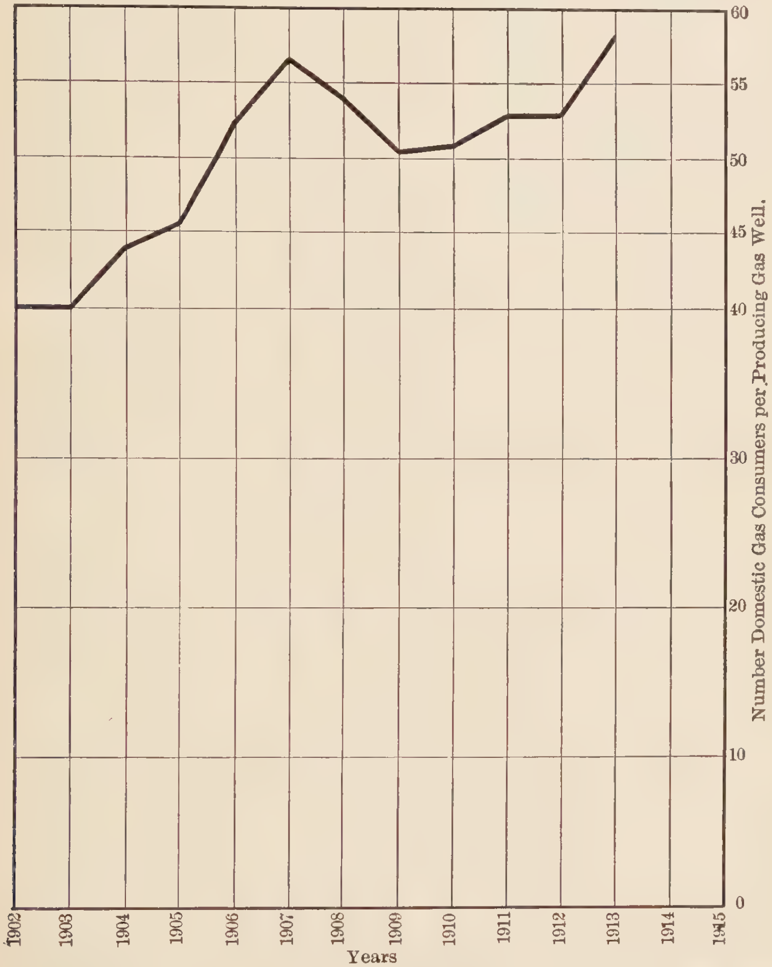

FIG. 76. Number of domestic gas consumers dependent for service on each natural gas well in the United States based on U. S. Geological Survey statistics.

tend to increase the cost of bringing gas to the city limits year by year. The drilling and production of gas in the fields is but a small proportion of the expense of delivering this commodity to the domestic consumer (Fig. 78). A public service corporation should be entitled to those rates which enable it properly to develop and conserve its gas supply. This rate should gradually increase for the following reasons:

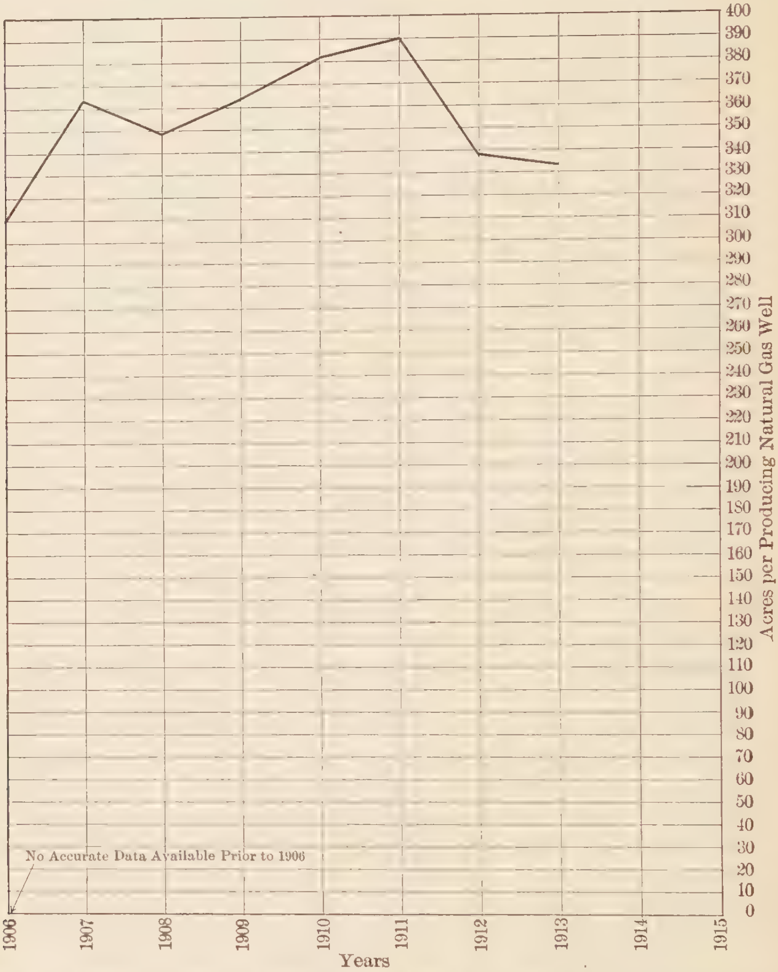

Fig. 77. Average number of acres of land held and reserved to protect and maintain each producing natural gas well in the United States, based on U. S. Geological Survey statistics.

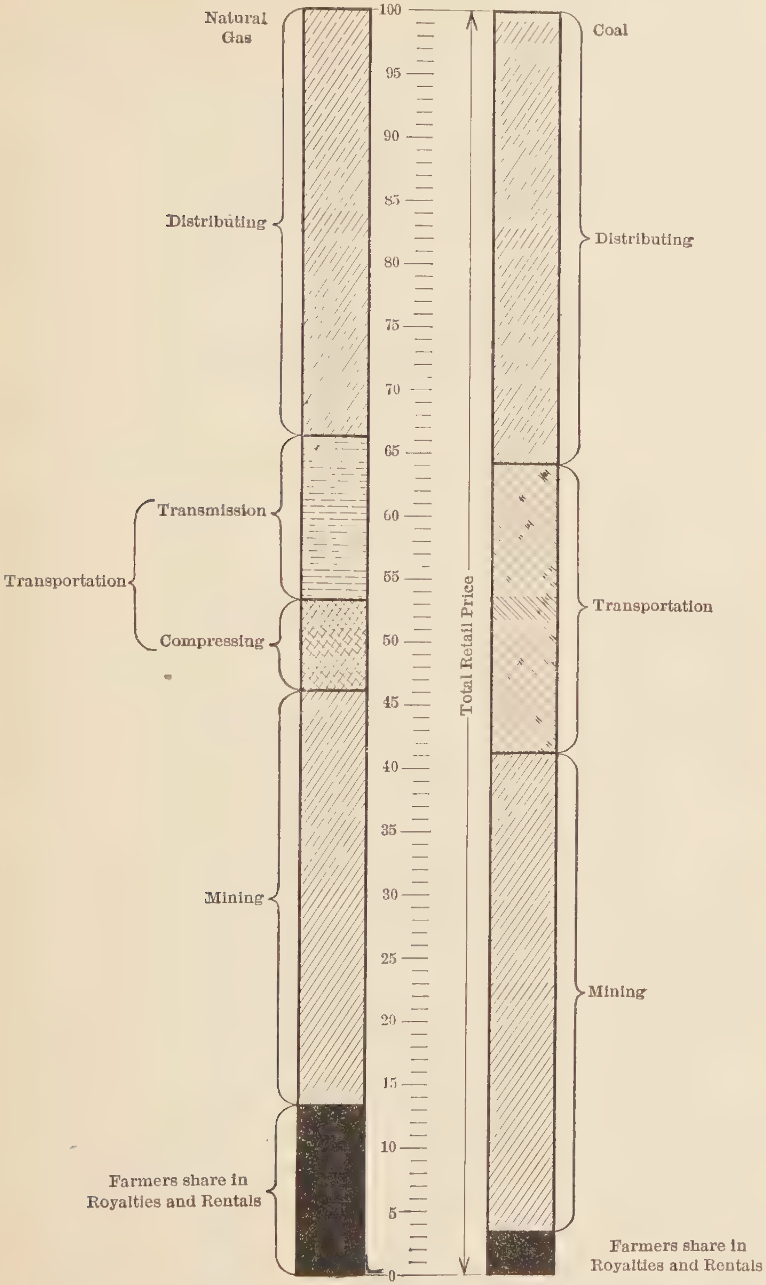

FIG. 78. Classification of total cost of natural gas and coal delivered to consumers.

(1) It is at present the lowest priced public service fuel, based upon the heat units delivered.

(2) The rise in the price of this fuel has not been in proportion to the rise in price of other commodities. (Fig. 79.)

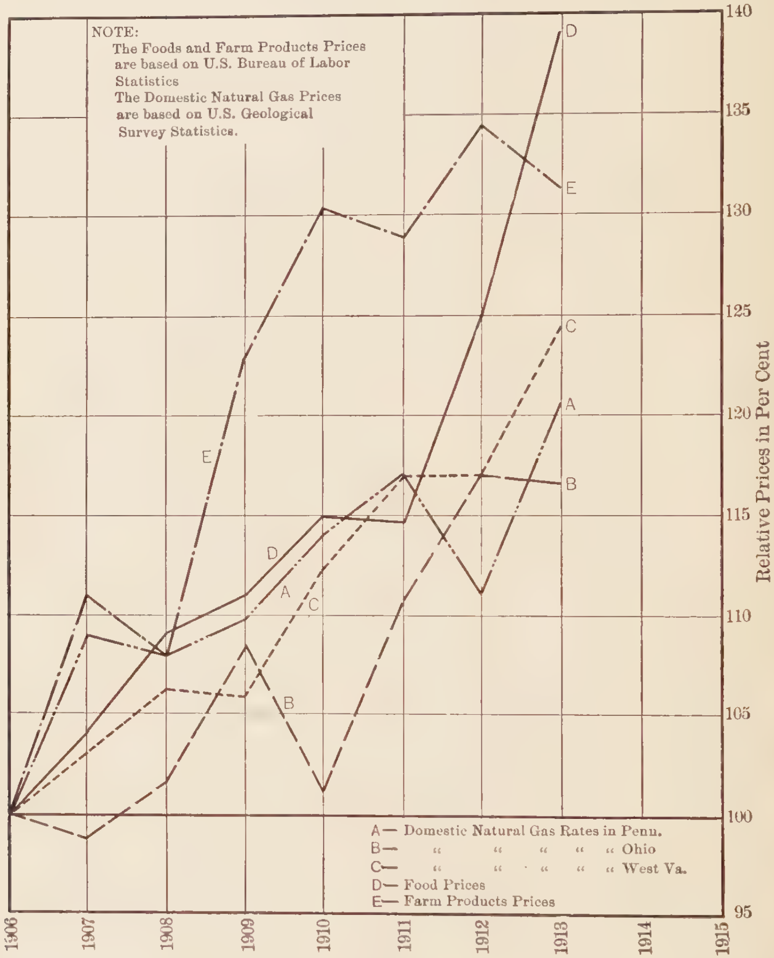

FIG. 79. Relative prices of food, farm products, and domestic natural gas service in West Virginia, Pennsylvania, and Ohio.

(3) A price more nearly in line with its intrinsic value, as compared with other fuels, would lead to less wasteful methods of use, and a better conservation of the supply.

(4) A higher price to the domestic consumer would make it possible for the gas

companies to restrict the sale of gas to such purposes, and eliminate the industrial user. This the large gas companies are eager to do. They state they would rather keep their wells and plants running at a minimum capacity during the summer months, than to sell this excess gas for industrial purposes at a cheap rate, if the domestic rates were such that they could do so. The underground supply would thus be conserved for the superior uses, and the life of the fields prolonged.

The following table shows the annual costs of typical 50 horse-power plants running 300 days at 10 hours and with two-thirds load, according to S. S. Wyer.

	Natural gas engine.	Fuel oil engine.	Producer gas engine (hard coal).	Steam engine.	Gasoline engine.	Electric motor.
Price of fuel	50¢ per 1000	5¢ per gal.	$10.00 per ton	$2.00 per ton	16¢ per gal.	3¢ per kw.
Horse-power hours per annum	100,000	100,000	100,000	100,000	100,000	100,000
Fuel per brake horse-power	14 cu. ft.	12 gal.	1.25 lbs.	10 lbs.	16 gals.	1 kw.
Amount of fuel	1,400,000 cu. ft.	12,000 gals.	62.5 tons	500 tons	16,000 gals.	100,000 kw.
Cost of fuel	$700.00	$600.00	$625.00	$1000.00	$2560.00	$3000.00
Six % interest	105.00	180.00	210.00	120.00	108.00	48.00
Ten % depreciation	175.00	300.00	350.00	200.00	180.00	80.00
Repairs and Incidentals	50.00	50.00	100.00	50.00	50.00	10.00
Labor	200.00	200.00	300.00	600.00	200.00	10.00
Total annual cost	$1230.00	$1330.00	$1585.00	$1970.00	$3098.00	$3148.00
Power cost per horse-power per annum	24.60	26.60	31.70	39.40	61.98	62.96

At the present time in West Virginia, one of the largest gas companies selling gas for domestic purposes is forced to produce more gas than it needs for such sales, particularly in the low-consumption summer months, and must sell this excess at low rates to industrial plants. This is brought about by the fact that another large gas company, whose gas is all used by the steel mills of the Pittsburg district, produces gas from the same pools and frequently from adjoining wells. If the public service gas company did not push production, the fields would in the end be exhausted by the industrial gas company, and the gas would be used eventually for the inferior purposes. If domestic rates were higher, the public service gas companies could afford to outbid the industrial company for leases, and the steel mills would go over to coal and producer gas to a large extent.

At the present time large quantities of gas are used for industrial purposes because of the relative economies shown in the table above.

The proportion shown by Fig. 81 indicates that 0.5 per cent of the total number of gas consumers are using more than 65 per cent of the total amount of gas produced.

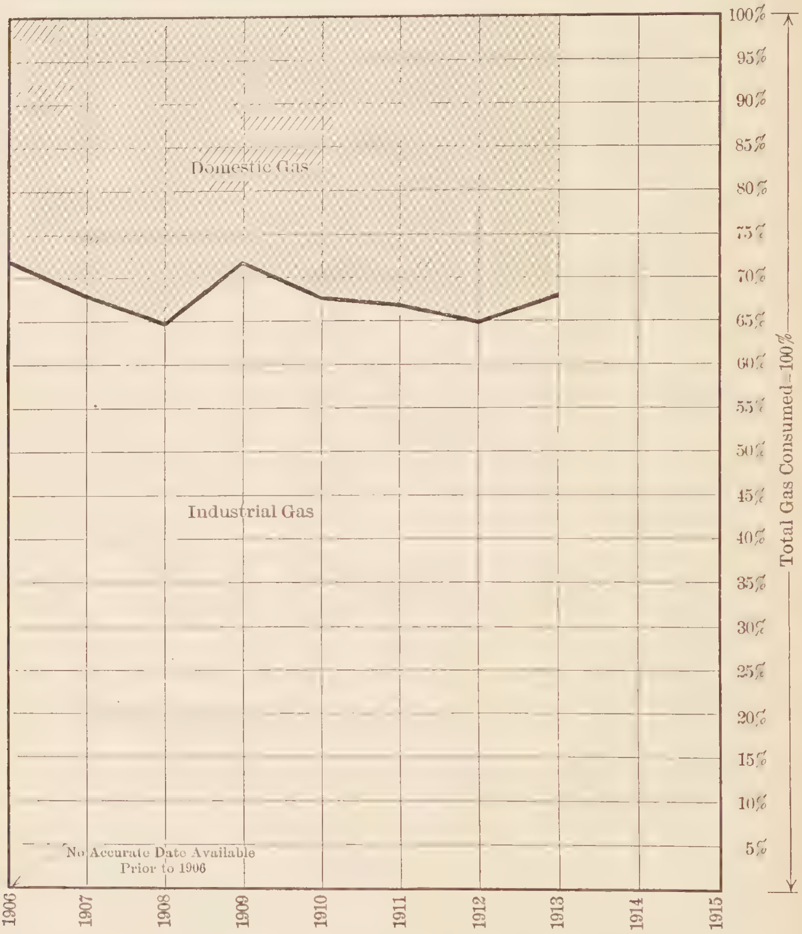

FIG. 80. Relation of domestic and industrial annual natural gas consumption in the United States, based on U. S. Geological Survey statistics.

The older gas companies took franchises and, strange to say, such franchises are still granted, which fix one price for a very long term of years. Such a practice is not only unsound economically, from the standpoint of the two parties involved, but it violates the principles of conservation. The difficulty lies, of course, in the ignoring of the patent fact that with rare exceptions caused by the striking of pools of gas of larger size or less depth than would be reasonably anticipated, the companies must face a gradual increase in the cost of production. This normal increase is the result of:

(*a*) The yield of the wells already drilled gradually decreasing.

(*b*) With the decrease of their pressure, heavy expense for installing compressors is entailed. (Fig. 86.)

(*c*) New wells which are drilled are increasingly expensive because:

1. Deeper.
2. On lands on which a higher bonus is paid on the average.
3. The new wells are on the average smaller.
4. The percentage of dry holes increases.

(*d*) It, therefore, becomes necessary to lay lines to more and more distant fields.

If no provision is made for an increase of the price to follow this increased cost:

(1) The service is discontinued, causing the substitution of coal or illuminating gas entailing the cost of new equipment and the use of either a more expensive fuel (p. 360) or a less satisfactory one.

(2) Or else negotiations are begun for a new contract. These negotiations are likely to be accompanied by litigation, itself a serious waste and an interruption to the extensive and proper maintenance of the service.

With a gradual, adequate increase of rate, the gas company is able to plan ahead and maintain those reserves necessary for the maintenance of the seasonal peak loads. (Fig. 72.)

The ideal franchise should be for a fairly long period of years but with adjustable rates. The adjustment of this new rate from time to time should be accomplished by a board appointed for the service, consisting of an engineer appointed by the city, or for the city by the State, with one appointed by the company, these two to select one or three more.

There is a tendency in every newly discovered gas field to repeat the history of the industry as a whole: (1) discovery, (2) over-production, (3) waste and sale for economically inferior purposes, (4) decline of production, (5) higher rates and more attention to efficiency of production, transportation and use. The states of Pennsylvania and Ohio, where gas was first used and where the greatest waste took place, are now importing a large proportion of their natural gas from West Virginia. (Figs. 82, 83 and 84.) This is also true of Kansas and Kansas City, Mo.,

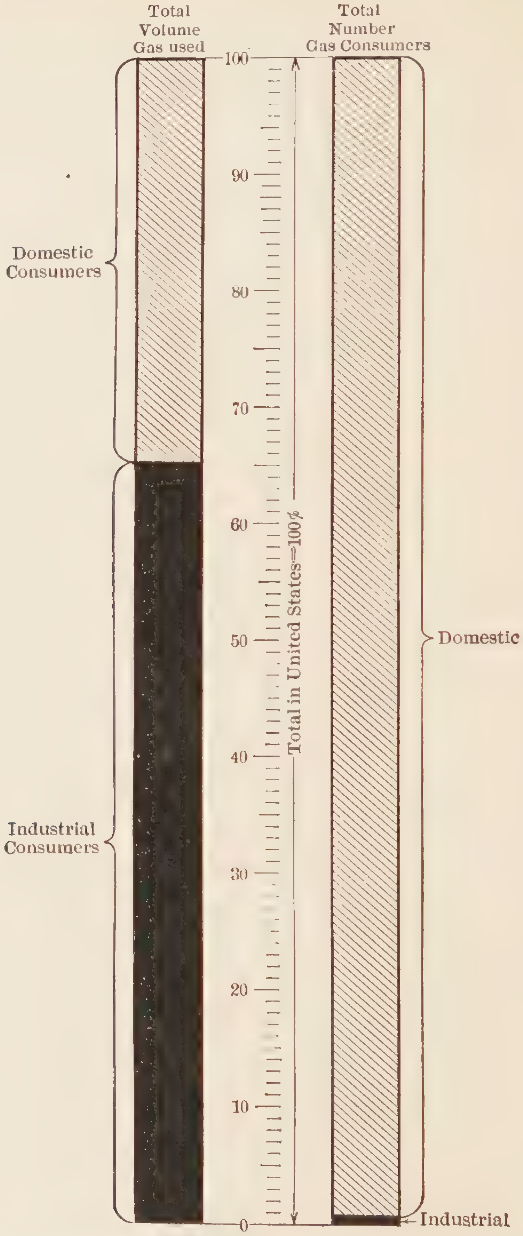

FIG. 81. Relation of domestic and industrial natural gas consumption in the United States, based on statistics compiled by U. S. Geological Survey.

where in the early days gas was in some cases practically given away to smelters and cement plants, while now Kansas City is largely supplied with gas from Oklahoma.

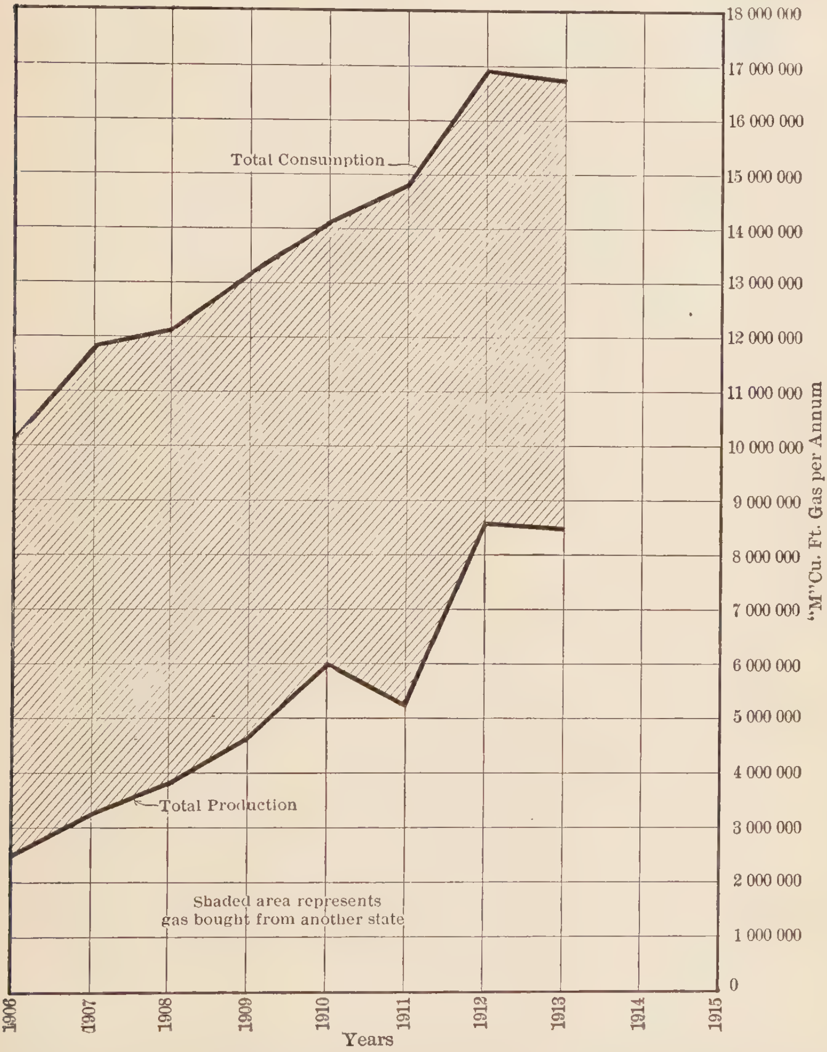

FIG. 82. Relative production and consumption of natural gas in New York State.

The industrial consumer of gas should look with suspicion upon the town which urges him to locate within its limits and at the same time offers as bait large quantities of free gas, or gas at a nominal rate merely. This is the same type of short-sightedness which led to the burning of flambeaux as a form of municipal advertising, and indicates an ignorance of the natural gas industry which leads to the dissipation of the gas in the field within a short time. The manufacturer will then find himself without any industrial gas whatever.

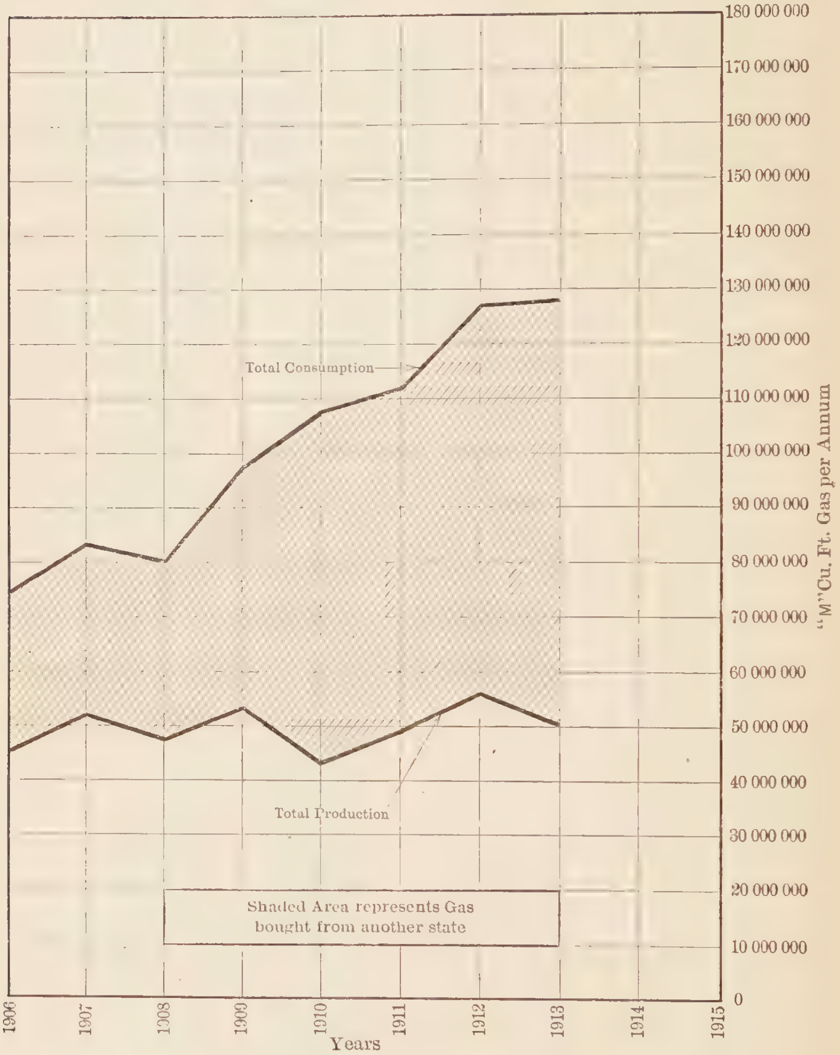

FIG. 83. Relative production and consumption of natural gas in Ohio.

The preceding paragraphs make evident the necessity of the control of natural gas by large well-integrated units. That is to say, the interest which controls the pipe line should also control gas production throughout large areas, and also preferably have a close connection with the distributing and marketing interest. Such an integrated unit has a

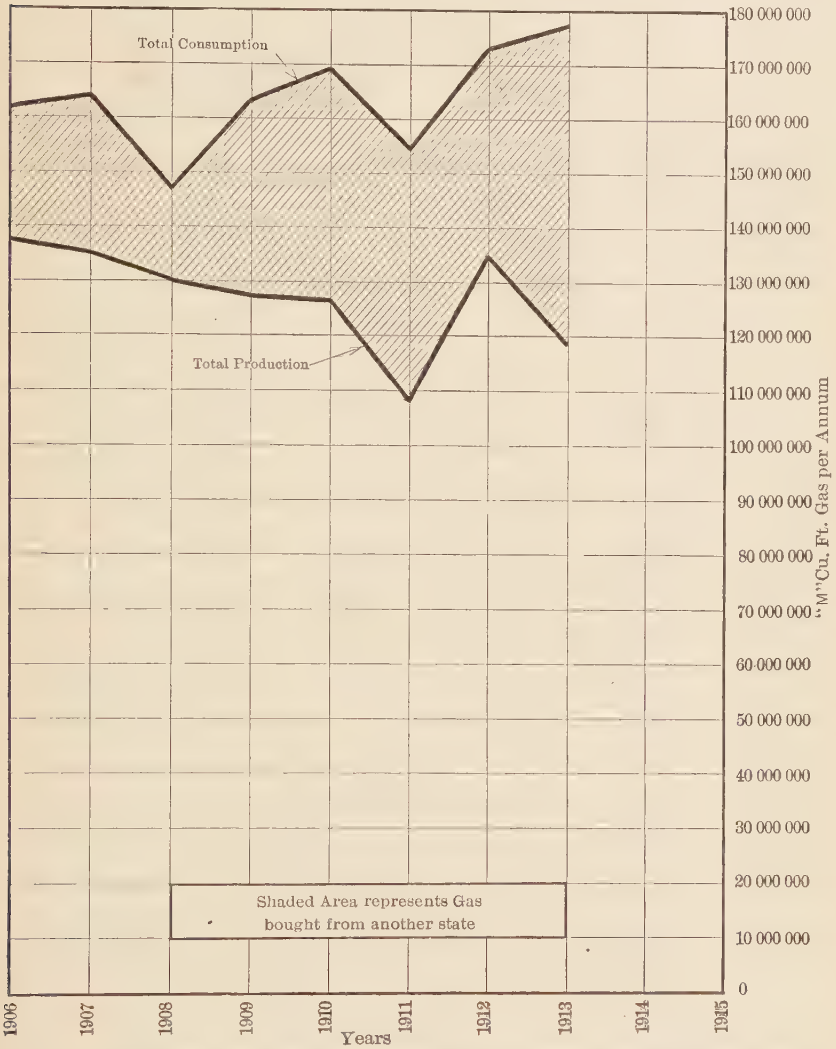

FIG. 84. Relative production and consumption of natural gas in Pennsylvania.

direct interest in conserving the supply of gas for future years, and where possible sells to the domestic consumer rather than to the indus-

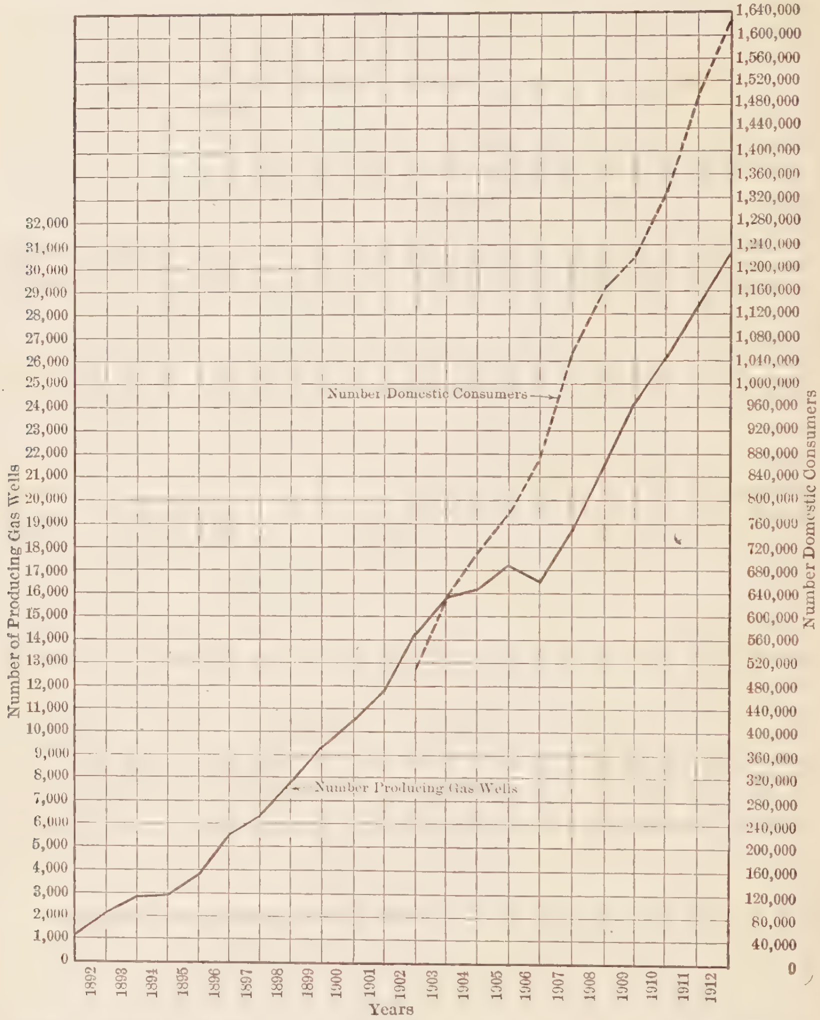

FIG. 85. Showing relative increase of domestic consumers and number of gas wells. The scales are not directly comparable.

trial user of gas. This has been proved in the history of gas development in Ontario.

Since cornering of commodities artificially raises prices, it has been frequently thought that companies might try to withhold oil and gas from use in order to force a scarcity price. This misconception is based on ignorance of the real situation, for quite the contrary is the fact. Oil and gas, by large companies as well as by small ones, are being brought to the surface too rapidly. Any arrangement which might lead companies to reserve some of their product in the sands would be an actual advantage, since both products are now being brought to the surface with too little

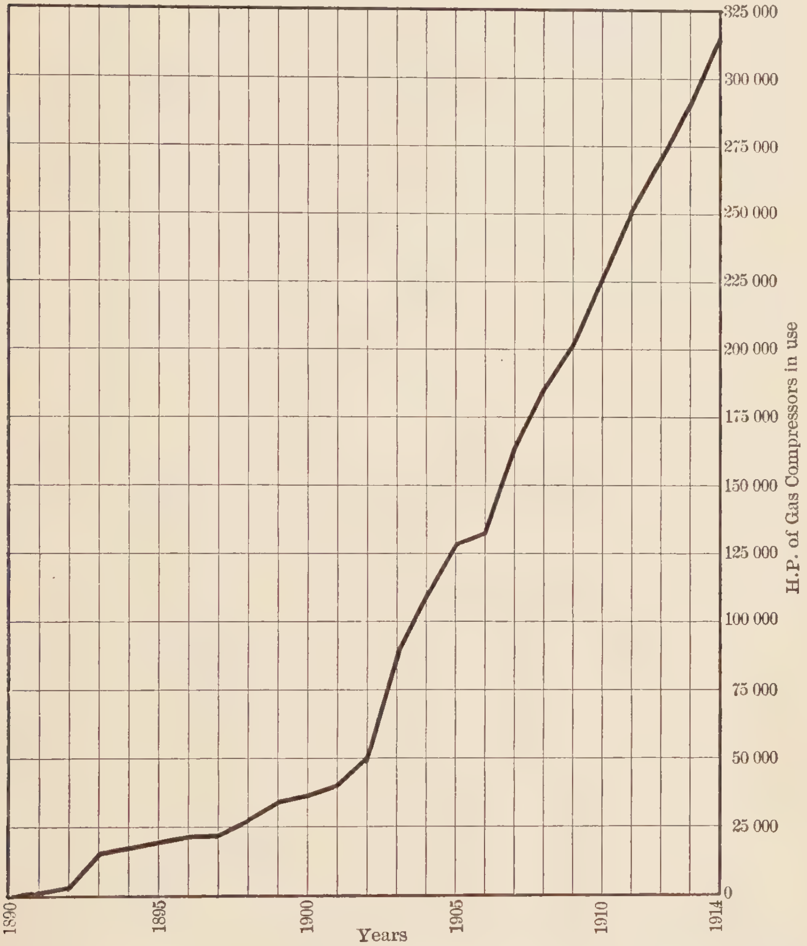

FIG. 86. Increasing use of gas compressors made necessary by increasing demands of natural gas consumers in the United States.

adjustment to need. Where several gas companies are scrambling for the gas from one pool, an agreement to restrict the output is a distinct public advantage, as is also an alliance between producing, transporting and distributing companies to permit marketing the gas in a distant city. Yet in some cases, such action has been held by the Department of Justice to violate the Sherman Anti-Trust law. Should this be sustained by the courts, the anti-trust laws should be amended to permit curtailment of output and to permit alliances for distribution of these two commodities for the public advantage.

Long pipe lines lead nearly always to a higher percentage of gas being used domestically with less being used for inferior uses. (Fig. 25.) The disadvantage of the greater amount lost in leakage is now being obviated by welding pipe lines and connections.

The efforts of various states to prevent the export of gas across the state lines is fortunately unconstitutional and has been so held. We see insidious efforts to accomplish the same result by the subterfuge of prohibiting compressors, high pressure, etc., and the vigilance of the courts is required for their detection.

The increased use of compressors has three great advantages. (1) It permits the consumption of a larger share of the gas by distant consumers away from the relatively near-by boilers and smelters.

While the introduction of compressor plants has been thought to represent a late phase in the history of pipe lines, as the wells near exhaustion, it is interesting to find them being installed earlier and earlier. This makes possible the utilization of the gas from the shallow sands that heretofore has been wasted on account of low pressure.

(2) Another advantage lies in the more complete extraction of the gas, for when the pressure of the gas in the well has been reduced to that necessary to move it at an adequate rate to the point of consumption, there still remains a great deal of gas to be extracted. Without compressors these wells would be abandoned even before they are as low as atmospheric pressure. A very serious obstacle to this complete extraction has been the passage of laws and litigation based upon an unscientific conception of the method, which is in reality strictly parallel to the pumping of oil wells. It is as absurd to try to restrict the production of gas to that which enters the lines by natural flow, as it would be to restrict the production of oil to that which flows naturally.

(3) One of the greatest agents in conservation is the encouragement of the gradual introduction of payment by meter rather than by flat rates. While it is obvious that the consumer's meter makes an incentive for

conservation on his part, we should also recognize that similar results are obtained where local distributing companies are obliged to pay by meter rather than on the basis of percentage of sales to consumers. Meters should be so placed that the companies in turn would find it to their advantage to keep the leakage low. Lastly, the producer's meter, which is now becoming more and more common, is an aid in locating leaks more easily and it also increases the incentive of the transporter to reduce leaks. Metering, then, whenever gas changes ownership, is one of the most valuable devices for conservation. It enlists the urgent effort of those who can do most to prevent waste.

CHAPTER XIX

SIZE AND SCOPE OF OIL AND GAS COMPANIES

Concentration. — The relative economy and efficiency of large and small producing companies is a matter of great interest and importance. The following theoretical considerations, as well as actual practice, all point to the overwhelming *advantage* of large units of capital and management.

The advantages are:

(1) Access to a much larger percentage of well records in the vicinity.

(2) Ability to employ more efficient and more highly specialized men.

(3) The considerable reduction in the number of offsets to be drilled.

(4) Ability to connect up the largest number of wells that each power is capable of pumping.

(5) Economy in labor, by having one pumper tend several neighboring powers.

(6) The more continuous utilization of the plant and equipment, such as pulling machines, for instance.

(7) Saving in time and teaming by maintaining well distributed and well stocked store houses.

(8) The ability to install a gasoline extraction plant, because of the company's control of the necessary number of neighboring wells.

(9) The conservation of pressure and the use of water flushing can be more frequently employed when the whole pool is owned by one company, or at most, by but a few companies whose managers could easily reach an agreement, which would be difficult were there, instead, many small lease holders.

(10) Important experiments can be tried, such as testing the relative merits of competing methods and materials.

(11) Economy of surveying.

(12) By holding several contiguous leases, instead of a few scattered ones, a large company may "feel out," from established production, location by location, relatively unhampered by property lines.

(13) By holding several contiguous leases, the large company is far less frequently forced to drill according to the terms of the lease, before the needed information is in hand.

(14) The logs in a large company are more uniformly recorded and are always available. Whereas, among many small companies, there are invariably some who keep very poor logs or hold them secret, and in some cases there are some who even falsify their records. By means of this fuller information, casing requirements and the proper depths of tests can be anticipated, sometimes saving an unnecessary hole, or preventing the premature discontinuance of one.

(15) Lower prices and better quality in supplies are possible when they are purchased in large lots.

(16) The economy of a large company drilling its own wells without letting them out to contractors. Or, if because of the difficulty of getting a competent superintendent of drilling, the company prefers to contract, this can be done at far cheaper rates than ordinarily, from the circumstance of there being many wells close together in one contract.

(17) A lessened danger from premature flooding by water from improper casing or plugging. Also less gas waste by small, irresponsible or incompetent neighbors.

Integration. — The foregoing considerations apply to the greater efficiency of concentrated or large producing companies. The following considerations indicate the higher efficiency which results from the integration of the industry, that is, the bringing under one management of the various successive steps in the oil and gas industry, such as production, transportation, refining and distribution.

(1) With integration, it would be possible to store oil in relatively few central, large, steel tanks, when otherwise, the oil would deteriorate more rapidly in numerous small, and more leaky tanks.

(2) Gasoline extraction plants, installed for handling gas from wells, might also recover gasoline from the pipe line company's storage tank vapors.

(3) By controlling, to a certain degree, the rate at which wells are drilled, the danger of overproduction may be reduced, and at the same time, the production may be better adjusted to the needs of the refinery.

(4) The oil and gas business should be in the hands of the same company, as otherwise the one-sided eagerness of the oil producer may not only lead him to waste vast quantities of gas, but also renders the search for gas more difficult and expensive on the part of the gas company.

(5) Pipe lines and laterals can be planned in a more systematic and farsighted way and be less frequently left without supplying leases.

(6) Water and fuel for pumping and drilling can be cheaply supplied from the nearest available source.

(7) The guarantee of a regular production for the refinery makes for greater economy and efficiency there as well as in the marketing of the oil.

Disadvantages of Concentration and Integration. — As a partial offset to these advantages of both concentration and integration, there are the following five foes to efficiency in all large scale business.

(1) Unwarranted favoritism in employment and promotion, which is however by no means unknown in small, industrial units.

(2) Slacking up, because the personal interest is less keen and vital.

(3) The temptation to sacrifice the interests of the company as a whole to those of officers, superintendents and foremen.

(4) Jealousy among departments or divisions of the company.

(5) A clique spirit that tends to advance the men already with the company, when sometimes new and valuable men from the outside are needed.

These difficulties are not necessary, and can be overcome in large measure by a high degree of executive ability on the part of the management. In practice, the losses from these five causes are evidently less than the gains, because, as a matter of fact, the large, integrated companies are constantly buying more properties, so that the percentage of leases held by great companies is steadily increasing.

CHAPTER XX

REPORTS UPON OIL AND GAS PROSPECTS OR PROPERTIES

The principal difference in reporting[1] upon an oil and gas prospect in an unknown region and upon an oil property in a producing district, is that in the former case more assumptions must be made based upon past experience in other fields. The difference is analogous to the difference between a report upon a mineral prospect and one upon a partly developed mine.

It must be emphasized here that no outline may be blindly followed by the engineer or geologist. Reports must be adapted to the clients for whom they are made. If to an investor, official or board of directors of limited technical knowledge, more explanatory details and illustrations must be included, and some points must be stressed, knowledge of which might be taken for granted in a report made for another engineer.

Again, there may be a decided lack of information obtainable along certain lines, due to physical difficulties, lack of time or limited opportunities. This again modifies the report. In a reconnaissance report it is frequently advisable to include recommendations for further examinations for certain data or in certain areas.

Some clients, whose operations partake of the nature of promoting, are prone to expect an engineer to commit himself unequivocally upon the merits or demerits of properties, and are particularly desirous that the former be stressed. If as is frequently the case there are conditions qualifying the favorable statements, there is danger that the prospectus may quote only the favorable paragraphs. Prospective purchasers or investors should always ask to see the entire report, or at least the entire summary, when only a part is quoted. The engineer should use direct, positive statements when these are warranted, since action is to be based upon the report, but at the same time he must use care that such statements are so worded as to give the least chance of producing a false impression in the mind of the reader, and thus impair confidence in the engineer's judgment.

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[1] Irving, J. D., "The Substructure of Geological Reports," Econ. Geol., Vol. 8, pp. 66–96.

Geography. — It has been customary, on the part of some geologists or engineers in reporting upon oil properties or prospects, to devote much space to a general description of the geography of the region. This is often advisable in a strictly scientific treatise, or may be so when the report is made for clients residing in a foreign country or those having no general conception of the country or field of operations. But such descriptions should generally be limited to those points having a direct bearing upon the geology or economic features of the oil or gas prospects of the region under consideration.

When the geography requires consideration, a few pertinent photographs often save many words, particularly if they are chosen to illustrate topographic features which are allied to the geology of the region and which at the same time mark certain limits to the oil prospects. Or they may be chosen to show the general topography and conditions of roads and means of transportation, particularly if it is a reconnaissance report with a description of physical conditions to aid future development. In little known regions, a report upon the location of potable water for camp purposes, upon navigable rivers or streams, or the accessibility of water for drilling purposes, is often desirable and may be included. These features are vital in some tropical regions.

Geological horizon. — In the consideration of the oil or gas prospects of a region, the geological age of the formations which can be reached by the drill is important. In Chapter III the relative value of these formations are discussed in the light of their past production. For instance, the Jurassic and Triassic of North America have never yielded oil or gas in commercial quantities, and as these sediments are principally of the continental type or metamorphosed, the chances are against the development of important pools in such formations except in the limited areas of marine production. Again, the Red Beds of Oklahoma and Texas are principally composed of shales with a small content of organic matter, and except in basal beds or near faults, where infiltration of oil from other beds is possible, they must be considered less favorable than the Carboniferous formations of those states. On the other hand, the Upper Cretaceous of Louisiana and Texas has been a prolific oil and gas formation at a number of points such as the Caddo, Corsicana and Thrall pools. Hence, when prospecting in areas which are underlain by these beds at drillable depths, there is a presumption in favor of their containing oil at points where structural and textural conditions are favorable.

The warning must be repeated here, however, that such a prejudgment either for or against formations of certain ages should not be carried from one region or continent to another, where conditions of deposition may have been different, without very good reasons. The example of the oil found in Argentine in Jurassic rocks has already been cited as an example of this danger.

The columnar section. — After the geological horizon in general has been determined to be favorable, the next important consideration in wildcat country is that of the columnar section. The most favorable condition is probably that of a more or less frequent alternation of sandstone and shale beds, the thickness of shale exceeding that of sand. A typical condition in southeastern Illinois is about 20 feet of sand, alternating with about 50 feet of shale. A section composed entirely of shale is unfavorable, as shale is seldom in such a condition as to yield its oil or gas content readily, or in other words, its contents are not concentrated sufficiently to yield oil or gas in commercial quantities. Exceptions are sometimes found such as the fissured shales of Colorado, and the fractured and jointed shales in the Gaines pool in Pennsylvania or in the Mexican fields.

Again, a section composed almost entirely of sandstone is unfavorable, as there has obviously been little organic matter deposited with the sands, and there is a lack of shale members which might act as a source of oil or gas. If in the event that such hydrocarbons were carried into a series of beds consisting principally of sand, from more distant sources above or below, they would soon be dissipated rather than concentrated in certain areas or beds.

A section composed entirely of massive marine limestones is not ordinarily favorable, because the accumulation of organic matter is so slow that nearly complete decomposition of the organic matter probably takes place so early that its products are dissipated rather than buried. Further, the interspaces between the particles of debris are so soon filled with secondary calcite as to reduce the porosity so that the limestone cannot act as a reservoir. However, under certain conditions such beds may later become suitable reservoirs for migratory oil. Such conditions are given as follows:

(1) Dolomitization of portions of the limestone.

(2) Jointing or fracturing of the limestone.

(3) Formation of solution channels, during an erosion interval, which may not be completely filled, or filled only with sand, at the time of submergence. Limestones which are irregularly siliceous are particularly subject to this action.

The attitude of the observed strata. — The principal methods of surveying and mapping the attitude or "structure" of the surface sedimentary formations, to determine the location, extent and degree of dip of folds, or other irregularities which may be expected to influence the accumulation of oil and gas in underground reservoirs, may be classified as follows:

(1) Alidade and plane-table.
(2) Aneroid barometer.
(3) Clinometer.

Plane-table. — In the first method described, an 18 × 24 inch plane-table is used with the Johnson-head tripod. A favored type of alidade is the miniature or explorer's model (Fig. 87).

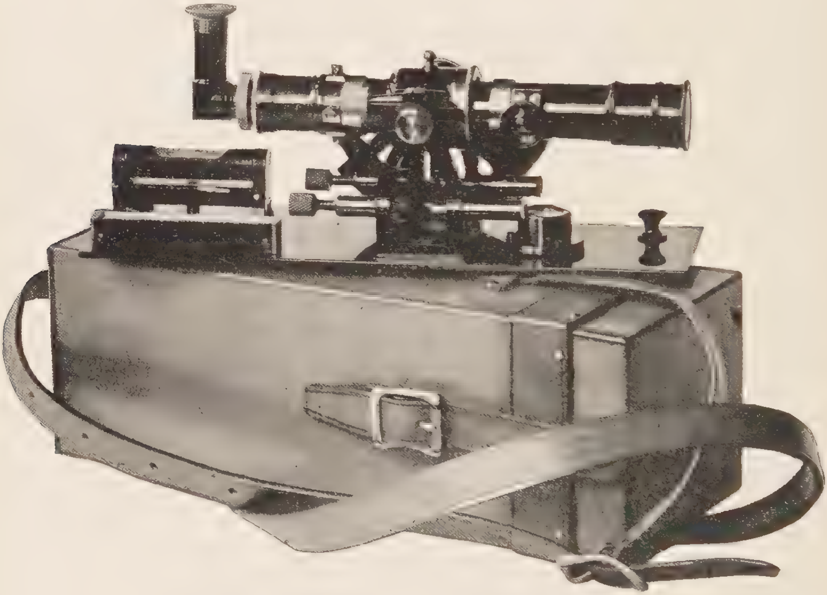

Fig. 87. Gurley explorer's alidade with case.

A plan which is becoming prevalent in the Mid-Continent field is to have the geologist carry the rod with a surveyor at the plane-table. This reduces the cost of having two geologists to each team and is much better than having the geologist at the table and a rodman on the outcrops, since the geologist in the latter case is frequently interrupted by the necessity of examining outcrops. A surveyor kept at this work increases in efficiency as he learns the requirements of following outcrops. The geologist must understand the operation of the plane-table, as he must use the plane-table map.

Sometimes the use of the plane-table is restricted to the construction of a base map in the preparation of a control sheet for the later use of the geologist. This base map may be made by a stadia traverse. Stations are marked by small surveyor's flags, or otherwise, and are used as bench-marks by the geologist, who may then work out from both sides with plane-table, aneroid barometer or hand level.

In developed territory that is already well mapped but lacks bench-marks, a good procedure is to use the spirit level in establishing the elevations of the wells and to use the land corners as bench-marks. In fairly level country the use of the spirit level is cheaper, and in countries of rugged relief, it is relatively more reliable than the rival methods.

In a few cases, where detailed maps are wanted by the company's officials at a distant point, it is advisable to prepare a topographic base map. In this case a plane-table is used in the preparation of the map, and the topography and some geological notes are taken simultaneously. These notes may be elaborated later. It is generally desirable to establish a few control lines with the transit to keep the errors within bounds.

Every oil geologist should be trained in the use of the transit, spirit-level and telescopic alidade, as well as with the less exact substitutes. The choice of method hinges on the local situation, and he should be prepared for any contingency, including the necessity of using any of these instruments without a surveyor or experienced rodman.

In the plane-table method,[1] the work starts with the establishment of a base line, in inadequately mapped regions, and follows the well-known method described in the surveying texts. But since much of the work of the oil geologist is in mapped territory, he starts with a U. S. topographic sheet, a township land map and a map of the properties and wells, and therefore he can profitably modify the ordinary, plane-table method. This modification is especially indicated since considerable error in his horizontal control is permissible, but all the accuracy in the vertical control that the alidade can give is needed.

[1] Wegemann, Carroll H., Plane-table Methods as Applied to Geologic Mapping, Econ. Geol., Vol. 7, pp. 622–637, 1912.

Stebinger, Eugene, Control for Geologic Mapping in the Absence of a Topographic Base Map, Econ. Geol., Vol. 8, pp. 266–271, 1913.

O'Hern, D. W., Some Suggestions as to Field Methods, Econ. Geol., Vol. 8, pp. 376–381, 1913.

Under these conditions, one or more of the three modifications following may be used.

(*a*) The base line is omitted, distances being scaled in by stadia.

(*b*) Side shots are located by stadia readings instead of by intersection.

(*c*) Vertical emphasis method. Instead of making every set-up on a point already located on the map, it may be a new point by sighting back to a turning point, which is entered on the map. The advantages in this last case are speed and the reduction of the vertical error, since the errors of back-sight compensate those of foresight.

The plane-table method makes it possible to keep a great deal of data upon the plane-table map, but even here, some at least of the stations must be numbered in order that notes concerning them may be entered in a note-book.

One method is to give each day of the trip a letter of the alphabet, and to number all points consecutively located on that day, as A_1, A_2, A_3, etc. As it is very important at times to preserve a record of all field impressions, such notes should include hypotheses which are suggested from time to time as the work progresses. This frequently prevents the necessity of going back over the field for more data, which is often inconvenient or impossible. It also tends to avoid confusion when all results are correlated in the office after the field work is completed.

Aneroid. — A method used by some geologists in certain fields is described by M. R. Campbell.[1] In this the aneroid barometer is used for all elevations, a profile traverse being run, upon which is shown, by graphic symbols, a complete record of all exposures. This method gives a maximum of information in a graphic manner, and is particularly useful where exposures are poor or where correlations between beds are difficult or obscure. Tentative correlation lines can be carried in the field, and changed or modified from time to time as new evidence is obtained. By carrying all points located on the map to the note-book, the horizontal scale of this profile is rendered unimportant. It is found convenient to use a scale sufficiently large to carry full descriptive notes on the same page above the profile. Suggested hypotheses and still fuller descriptions, with reasons for correlations, should be carried on the left-hand side of the note-book. This system of note taking is very elastic, and can be modified by carrying detailed sections and sketches in connection with the profile. It obviates the necessity of following one or possibly two key horizons, as a sufficient number of intervals are taken in each area to make it possible to calculate elevations for the key beds even where they are not recognized.

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[1] Campbell, M. R., Trans. A. I. M. E., Vol. 26, p. 298.

Care must be exercised in using the barometer that it is frequently checked upon a bench-mark, especially during a day when pressure conditions fluctuate rapidly. For the same reason it is important to take the elevation of all road corners or trail intersections, or other points where succeeding traverses furnish an opportunity for checking readings. In fact, a series of bench-marks can be established by the aneroid barometer, if enough readings are taken on different days, and preferably at different hours, and the result may be averaged, after suspicious readings have been rejected. This may be done along main roads which are traversed frequently. Many geologists depreciate too severely the reliability of aneroid elevations taken in geologic surveying. The best results are obtained if care is taken in the following points:

(1) Get a good instrument, compensated for temperature, and with a needle which is neither too sensitive nor too stiff, with the dial graduated to 10 feet.

(2) In cold weather, always carry the instrument where it may have a nearly uniform temperature, as in the vest pocket.

(3) The barometer should be carried so as to avoid jolting as much as possible.

(4) In tapping the barometer to free the needle at each reading, do so lightly at the same place and as nearly as possible in the same manner at all times.

(5) Readings should be taken by looking directly down upon the needle, as the position of the eye on one side or the other may cause a difference in the reading of five feet either way.

(6) When going up or down hill rapidly, two readings should be taken at each point, as some instruments have a certain amount of "lag." The later reading should be used.

(7) One should never go more than a short time without checking the aneroid upon a bench-mark. This may be a government bench-mark along a river or lake, a railroad bridge or station, the elevation of which may be determined later, water level if along a coast, or other points for which the elevation has been previously determined. In emergencies a series of bench-marks may be laid out with the aneroid itself.

(8) It is advisable to take a time reading with the barometer reading; the error between bench-marks may then be distributed between points according to the time the reading was taken. In other words, the curve of atmospheric pressure variation is roughly proportional to the time during which the variation takes place. Plotting the reading and time on cross section paper is advantageous when the period is unduly long.

(9) Barometer readings should be taken at all road corners or points where traverses will be likely to intersect. One should go out of one's way to check the barometer on a known point of a previous traverse. This aids greatly in eliminating errors in interpolation.

(10) Where a barograph is available, it will be useful in interpolating the time readings.

The aneroid method is most useful where a good topographic base map is available, or where frequent bench-marks are available. However, in reconnaissance work in foreign countries, where assistants are not available and no good base map procurable, the aneroid method has been used in connection with a compass traverse with satisfactory results. Distances are determined by pacing, while the location of main points is determined by triangulation with a Brunton compass. Compass traverses are run on all trails. The notes for the control are carried directly above the geologic profile, upon which are shown all outcrops by a modification of the Campbell method. The limits of error of such reconnaissance methods are not unduly large if used with sufficient care, although they cannot be recommended to the novice.

On the other hand, the plane-table method is most useful where there are one or two key beds having many outcrops. It is not adapted to wooded country. It does not allow the nice balancing of evidence which is possible in the continuous profile method, unless the latter method is used in conjunction with the plane-table. Unless there is a sufficient number of clean-cut outcrops in an area which can be covered by a set-up, the method is relatively slow and cumbersome. It is, however, slightly more accurate; and where dips are steep, so that the horizontal distances are important, it is the preferable method.

In unmapped territory the plane-table method is frequently desirable for the more complete map thus obtained is valuable to the company for other than geologic reasons.

Clinometer. — The use of the clinometer is indicated where the dips exceed about 3 degrees and is especially important where identifiable key horizons are lacking. This condition is frequently met in the Fort Smith (Arkansas) — Coalgate (Oklahoma) gas field, and in the oil and gas fields of Colorado, Wyoming, and California, but seldom elsewhere in the oil fields of the United States.

The clinometer most used is the Brunton pocket transit. It should be laid on a flat surface; a small square of hard rubber or plate glass is best. The clinometer on the plate must be laid along the line of dip. This is quickly determined by dropping a few shot and noting the direction in which they roll. The greatest care is necessary in selecting a representative surface and in avoiding one that has heaved out of place or one that represents cross-bedding or one that is modified by erosion.

The sites of clinmometer readings are generally harder to locate upon the map than the sites of aneroid readings, because they are taken more often in regions inadequately mapped. Recourse is, therefore, more common to the device of location by taking bearings upon two or three land-marks, either natural or established for this purpose on conspicuous hill tops, etc. These land-marks may then in turn be located from others or from land corners, but it is best to trust the pocket transit only for stations which are not used for the location of other stations. When the pocket transit must be used for many long sights, it is well to mount it on the light photographic tripod now supplied with it.

Convergence and attitude of the sand. — The attitude of the oil or gas sand may differ from that of the strata exposed at the surface because of convergence or lack of parallelism. This may be brought about by one of two causes:

(1) An intervening unconformity, which may be either a sedimentary overlap
 (*a*) without tilting during the hiatus,
 (*b*) or following tilting.
2) Thickening or thinning of the intervening strata of the key bed or of the sand.

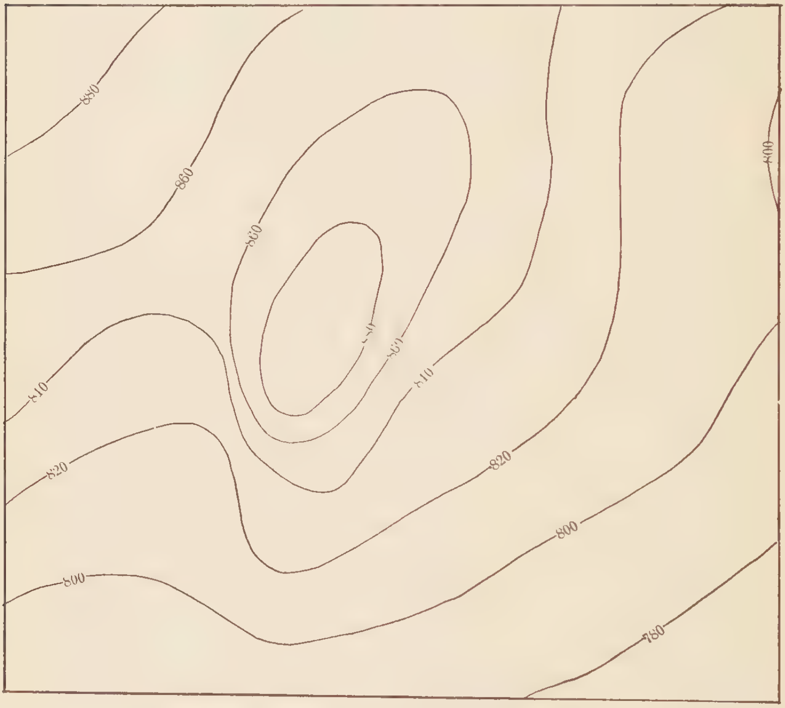
Unless the lower beds outcrop near-by, and give enough evidence at the surface from which deductions can be made as to the extent and character of an unconformity in its relation to the oil or gas sand, or unless sufficient drilling has been done in the surrounding country to furnish this information, it is difficult for the geologist to make predictions as to the depth or attitude of beds below an angular unconformity.

A sedimentary overlap necessarily produces convergence, so that when its direction is known, calculations as to the attitude of beds below such an overlap in relation to the surface formations are possible.

Local sedimentary gradients peculiar to individual reservoir beds are frequently large enough to affect the accumulation of oil or gas in such reservoirs and may counteract the effect of small folds. They cannot be predicted from the surface attitude.

A general convergence between beds may, however, affect an entire field, such as in central and southeastern Ohio and in the Oklahoma fields. From scattered wells the rate of this convergence may be calculated for any particular region. For example, a key bed at the surface and the oil sand may tend to diverge at the rate of 10 feet to the mile. Where a number of well records are obtainable in the vicinity of the tract where the attitude of the surface bed is known, the local irregularities of this general convergence may be plotted on a convergence sheet by means of isobaths showing the lines of *equal interval* (isochore). This is drawn upon transparent tracing paper to the same scale as the map used, and is superimposed upon the map on which the structure contour lines are drawn upon the surface key bed (Figs. 88 *A*, *B*, *C*). Where an isochore on the convergence sheet crosses over an isobath, the elevation of the oil sand above or below sea level (or other datum plane) is determined by

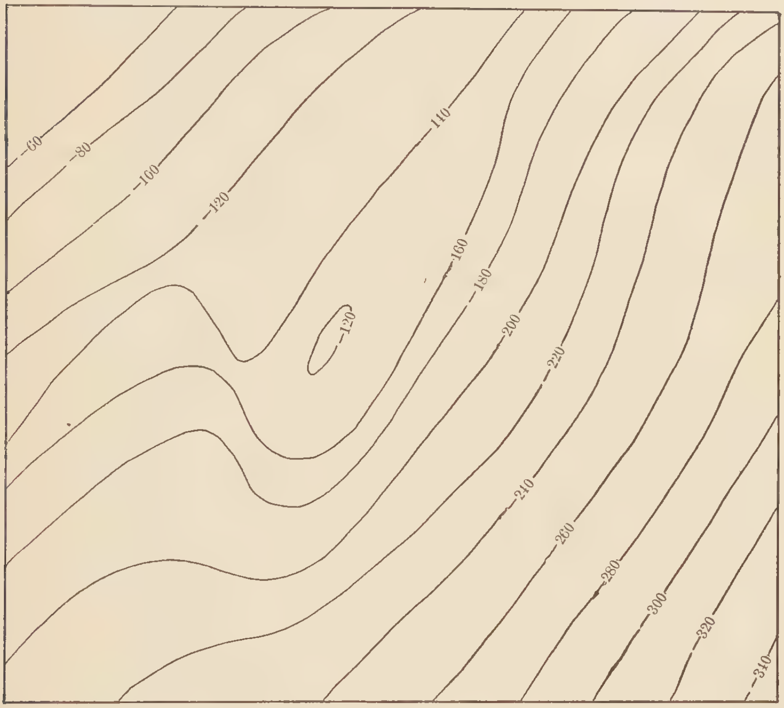
$$\left.\begin{array}{l}\text{The elevation of the}\\ \text{key horizon}\end{array}\right\}\text{ minus }\left\{\begin{array}{l}\text{The interval between the beds as indi-}\\ \text{cated by the isochore}\end{array}\right.$$



Structure contour lines drawn on a surface bed.

A

This gives a new elevation or point for a new isobath on the oil sand. The convergence of beds is frequently enough to counteract seriously the apparent promise of relatively small anticlines, domes, or other small flexures (Fig. 88). Where beds are dipping steeply and at the same time converging, careful calculation is necessary to plot the structure or the attitude of the oil sand so that the position of the crest of the dome or anticline may be known. It is not directly below the corresponding crest as shown in the surface beds, even though the anticline is symmetrical.



C

Structure contour lines drawn for the producing sand, as calculated from *A* and *B*.

Fig. 88. — *A*, *B* and *C*. Method of constructing isobaths for the sand by means of a convergence sheet.

Gas, oil and asphalt at the surface. — Gas, oil or asphalt which exudes at the surface may be significant of any one of a number of conditions:

(1) If the gas is high in nitrogen or carbon dioxide and low in hydrocarbons, it may have a solfataric origin. But natural gases in the Kansas fields are known which have a nitrogen content of 80 per cent of their volume; hence such evidence is not conclusive.

(2) If the gas has an oily smell or is accompanied by oil, it may indicate a fault or fracture at the surface connecting with a deeper reservoir.

(3) Inspissated oil in the form of bitumen or asphalt may indicate the outcrop

of oil-bearing beds which may be prolific at other points where they are under sufficient cover. On the other hand, it may merely indicate that oil has existed in such beds at a previous time, but has been dissipated. Heavy oil is found in the California fields in steeply dipping beds but a short distance back from asphalt seepages at the outcrop. But in horizontal beds in the Athabasca River in Alberta, the sand-body is generally under so slight a cover that no adequate pressure exists which might act as an expulsive force for the very viscous oil, and wells drilled close to the "tar sand" outcrops have been failures.

(4) Asphalt or bitumen, found at the outcrop of beds which offer but poor chances for the concentration of oil or gas, should not be taken too seriously. A section composed almost entirely of sand strata is a case in point.

(5) Oil or asphalt found in igneous rocks has probably originated in near-by sedimentary formations. These latter formations, or in rare cases the contact, should be prospected rather than the igneous rock.

In general, oil seepages from the younger formations, such as the relatively unconsolidated Tertiary or Cretaceous, are more significant as to the existence of near-by unexhausted reservoirs, than are such residues found in the outcrop of older rocks. In the younger rocks there has not been so much erosion, nor so much time since the last tectonic change for the fluid and gaseous contents to reach a state of relative equilibrium. This has long since been reached in the case of the Carboniferous formations for example. In the latter case, deposits of solid bitumen are found in West Virginia in beds where all volatile constituents have long since been dissipated. The same is true of similar deposits in the Wichita and Arbuckle Mountains in Oklahoma, found in Carboniferous formations. In both cases, the oil pools in the same formations are usually found many miles from the occurrence of these petroleum residues.

However, later tectonic or gradational changes may sometimes disturb even such old formations and may allow the escape of oil and gas from old reservoirs recently opened. The oil found in the Carboniferous strata of the San Juan district in Utah is an example of this. Here outcrops sealed with asphalt and paraffin occur but a short distance from producing wells.

In reporting upon a district all such surface shows should be described, as well as their probable origin and significance as to underground accumulations. It frequently happens that these surface seepages are the primary reason for having the report made, and land on which they occur has sometimes been taken up rapidly before the geologist or engineer has been called upon. He may, therefore, have to overcome a certain amount of skepticism in condemning the areas immediately surrounding the seepages, if they are merely outcrop seepages.

Seepages at outcrops may represent the eroded crest of a fold, and while drilling will not develop production in the outcropping bed near the seepages, yet underlying beds may be promising. Where seepages presumably indicate a fault or fracture line, which is not clearly indicated at the surface by other evidence, there is danger that the exuding oil or asphalt may have traveled laterally for some distance through porous beds or channels before reaching the surface. Recommendations for the location of wells on such evidence alone is unsafe. A number of dry holes have been drilled in the Mexican fields just on this inadequate evidence.

Extensive drilling, as well as examination of outcrops, often determines certain definite characteristics peculiar to a productive horizon, and these may be found to persist throughout large areas. These characteristics are important in a report which attempts to appraise an oil property, particularly in advance of complete development.

For instance, reservoirs in certain sand horizons are known to lose their pressure rapidly, and all wells producing from such an horizon are short-lived. Such reservoirs are evidently local and very much restricted in extent, although the porosity may be favorable. On the other hand, the Clinton sand in Ohio is a very fine-grained sand, uniform in texture, without water. Other sands contain water high up on the flanks of all folds. The reservoirs in some sand horizons contain relatively much more gas than oil, while in others, such as in most of the Illinois fields, the reverse is true. Others may be entirely gas sands, such as the Dakota sand in certain districts in Alberta. The Hundred-foot sand in Pennsylvania is a thick sand-body of which the major part is tightly cemented or water wet. The oil pays are relatively thin, irregular gravel, or pebble beds included in the finer-grained main sand-body (Fig. 23).

The Bartlesville sand in Oklahoma consists of a succession of lenticular sand-bodies, which are frequently oblong. As the general shape and trend of the sand-bodies at a certain horizon are likely to be in a direction corresponding to the old shore lines at the time of deposition, and as such directions are sometimes in line with later folding, there is frequently a decided correspondence between the long axes of sand-bodies occurring at such horizons and the axes of the folds. These considerations led to the attempt on the part of early operators in the Appalachian fields to attach a great deal of weight to 45 and 22½ degree lines in locating wildcat wells or in "feeling out" from proven territory in development work. These directions changed as the northern limits of the Appalachian basin were approached, not only in the direction of the long axis of the sand-bodies but also in the direction of the flexures which prevail in those more distant regions. Even in the older fields too uncritical a use of such belt-lines was unsafe, as some horizons showed irregular sand-bodies whose origin was evidently in sandy hooks and projections from the old coast line. Pools have thus been developed which straddle the folds and intersect the former shore lines at high angles.

Other horizons, such as the Wall Creek sand of the Wyoming fields, are sheet sands, and water encroachment occurs rapidly. In some, strong jointing allows the oil to move more readily toward wells located in certain directions; or this movement may be along fracture or fault lines, as in the Mexican fields, with the attitude relatively unimportant.

The individuality of sands is further shown by the fact that some require shooting before they will produce readily, while in others there is enough fine clay in the sand to clog the face when it is compressed by the shot. Other sands may be more or less unconsolidated and tend to set up drainage channels. Some sand horizons are famous for the high yield per acre-foot, while others are poor. Certain physical conditions give the key to these variations, and should be considered by the petroleum engineer or geologist in reporting upon an oil property.

Comparison with neighboring properties. — There are many questions with regard to developing an oil or gas property, or in appraising such properties for purchase or sale, which can be answered by careful comparison with neighboring properties in the same reservoir, or properties similarly situated in other reservoirs in the same productive horizon. Among these are the following:[1]

(1) Production decline curve.
(2) Pressure decline curve.
(3) Yield per acre-foot of sand.
(4) Number of productive sands above and below the main "pay," and their characteristics.
(5) Cost of operation (drilling and producing).
(6) Percentage of dry holes.
(7) Most efficient spacing of wells.
(8) Number of wells to be drilled annually to keep production up to a certain figure.
(9) Logs of wells, showing principal water sands, and best casing procedure.
(10) Records of any deep holes, for data as to the possibility of deeper production.
(11) Most efficient methods of oil recovery for the district.

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[1] Hager, Dorsey, Min. & Sci. Press, Dec. 9, 1911.

Costs. — These may be obtained by comparison with other properties in the same district or in similar districts, making allowance for differences in physical conditions which might increase or decrease the costs for the property under examination. There is always a considerable variation in development costs, as there are so many elements of uncertainty. It is well not only to figure average costs for the district, but also maximum costs for individual wells, as a factor of safety, especially if the engineer is reporting to clients who have not developed an efficient operating organization, or where only a few preliminary wells are to be figured upon.

The cost of oil production can of course be figured much more closely than can development costs. It must be remembered, however, that the cost per barrel of producing oil varies with the production of the wells, whether flowing or pumping, with their depth, the frequency of cleaning, the amount of sand in the oil, the gravity of the oil, amount of tankage necessitated by marketing conditions, etc.[1]

Marketing. — The value of an oil prospect or an oil property varies with differences in the following factors, which govern the ease of marketing the oil produced:

(1) Gravity of the oil, and its percentage of light constituents, gasoline, etc.

(2) If fuel oil, the distance from the point of consumption, and the size of the market at such point.

(3) Whether there are pipe lines[2] to the seaboard, or rail connection, or whether these must be built.

(4) Over-production or under-production, and prospects for the future.

(5) Whether political or other conditions will interfere with obtaining a right-of-way for pipe line.

(6) Whether or not there is competition among several refineries or pipe lines, or lines of tank steamers to take the oil.

If several of the above conditions are unfavorable, it of course does not pay to prospect or develop new territory where the chance of obtaining reasonably large wells is small. For instance, it would not pay a company to prospect for oil in Colombia, if the geological indications were that there would be a large percentage of dry holes and that any wells that might be successful would be no larger than those being drilled in the Appalachian fields. Particularly unprofitable would it be, if in addition to the small size of the wells, the oil was of an inferior grade. Where the line should be drawn requires a careful balancing of evidence based upon all the information obtainable — geology, climate, transportation, topography, drainage, land titles, labor, political concessions or antagonism, as well as the possibility of future production or export taxes, whether the cost of getting the oil to the nearest market will allow it to compete with the domestic oils in that market or oils imported from other fields.

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[1] Requa, M. L., Bull. A. I. M. E., Feb., 1915, pp. 217 and 739.

[2] Federal Trade Commission. Pipe-line Transportation of Petroleum.

Use of models. — In addition to the graphic methods which may be applied by the petroleum engineer is the model. A common form is that of the "peg" model.[1] This consists of a map of the developed area in a pool with pegs inserted for each well. These pegs are divided into sections to scale and colored to represent the different formations. Or possibly it is advisable to show only the "pay" sands. It may be added to from time to time as development proceeds, and may even have glass sides on which are represented the formations in more detail. Further than this the transparent model is not particularly adapted to oil and gas problems.

It is sometimes difficult to explain to operators the significance of structure-contour lines; and foreign clients have not as a rule become accustomed to this method of representing structural folds. While such maps may be supplemented by geological sections, it has sometimes been found a further advantage to have plaster models constructed by a professional map maker, showing the surface topography, which lifts off as a separate section, with the "lay" of the underlying oil sand below. This is of advantage in showing convergence between beds, or other underground problems, such as faults or strongly marked unconformities in relation to oil accumulations. A geological section is in only two dimensions, while the model has the advantage of showing the entire problem at a glance. Fig. 90 is a photograph of such a model, showing the "lay" of the Hundred-foot sand in the Fairmont district in West Virginia. This cut shows the upper topographic section removed. Fig. 89 shows this in place, and also shows to the right the top relief section of a model of the Frazeysburg Quadrangle in Ohio. The topographic relief in both cases is based upon U. S. Geological Survey quadrangle maps. In Fig. 90 one sees that each contour drawn upon the top of the oil sand is indicated by a "terrace." That is to say, the slope is not graduated between contours, giving a somewhat unnatural appearance. It has been found that a better method is to show an even natural slope to the sand, the contour lines being merely drawn at intervals corresponding to 20-foot or 50-foot changes in the elevation as the case may be.

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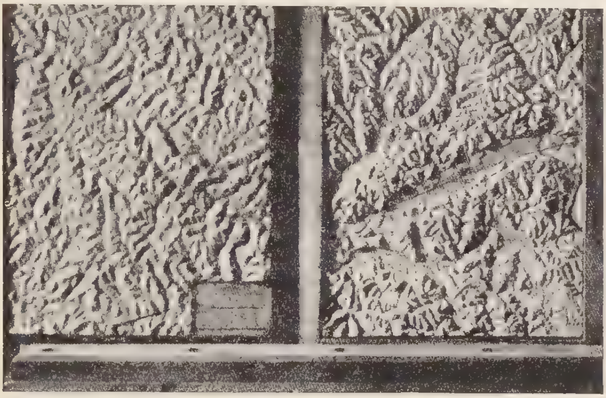
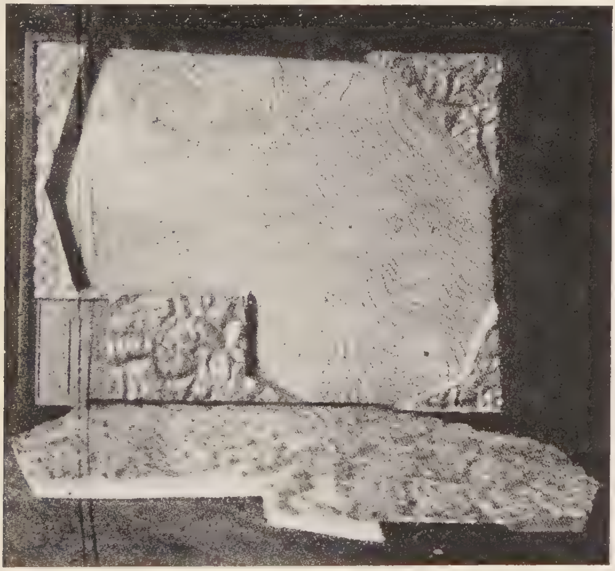
[1] Western Engineering, Nov., 1915, p. 201.



A *B*

FIG. 89. Topographic models of Fairmont (*A*) and Frazeysburg (*B*) quadrangles.



C

FIG. 90. Model with section removed showing "attitude" of the producing sand of a Fairmont quadrangle.

Maps. — A report should always be accompanied by maps. One should cover a large area to show the relationships of the different areas represented in the more detailed maps. Where there are wells already, they should be indicated on at least one of the maps. Unfortunately there is some discrepancy in the choice of symbols used, and they are frequently too few to suffice for all the data which should be given. It is very desirable that a joint committee of the American Institute of Mining Engineers, the American Petroleum Society, and the U. S. Geological Survey adopt a uniform system. The senior author has collated[1] the several systems and has suggested certain improvements.

Names of sands. — The writer of a report is frequently embarrassed by the lack of names, by which he can designate certain oil and gas sands, by a loose application of names, when they do exist, by a variety of spelling, or in other cases by a burden of synonyms. The senior author has advocated[2] the use of the name of the owner of the land, where the discovery well for that sand was first found productive, unless of course usage has already established some other name.

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[1] Johnson, Roswell H., Marking Oil Maps. Economic Geology, Vol. 5, pp. 273–277.

[2] Johnson, Roswell H., Oil Sands of the Mid-Continent Fields. Oil and Gas Investors' Journal, Vol. 8, pp. 27–28.

CHAPTER XXI

THE VALUATION OF OIL PROPERTIES

An oil property may be said to have two values, or to have value in two different senses. First, there is the *exchange value*, that amount for which it can be sold; and second, its *productive value*, or the amount of present capital which the income can repay with that rate of interest necessary to attract capital to such ventures, including the consideration for risk. These two values are seldom the same, and the skilful appraiser endeavors to ascertain each value, so that if the exchange value is the higher he can recommend the sale of the property; if the lower, its purchase.

In determining a selling price, the appraiser should ascertain the productive value as his basis, because he should not sell *below* this. The mere broker is tempted to feel satisfied if he knows only exchange values; but if he does not understand productive values, he may sell too low and he may not foresee fluctuations in exchange value caused solely by changes in productive values.

The productive value of an oil property is, of course, determined by the gross profit which may be expected from it. This gross profit varies directly with the size of the revenue and inversely with the size of the outlay.

Outlay. — The outlay may be classified as follows:

(1) To purchase.
(2) To retain, if undeveloped.
(3) To develop, if undeveloped.
(4) To continue development, if obtained partly developed.
(5) To put into a satisfactory condition, if purchased wholly or partly developed.
(6) To maintain.
  (*A*) Regular maintenance:
    (i) Wages.
    (ii) Supplies
    (iii) Transportation of supplies.
  (*B*) Occasional outlays:
    (i) Pulling and replacing cups.
    (ii) Cleaning.
    (iii) Miscellaneous.

- (*C*) Accidental outlay:
    - (i) Wind.
    - (ii) Lightning.
    - (iii) Fire.
- (7) Taxes.
- (8) Share of general expenses.

These factors are treated in turn.

(1) *To purchase.* — The purchase consideration may be fixed or contingent. If fixed, it is sometimes, although rarely, wholly in cash, but more frequently partly in cash and partly in deferred payments. A majority of sales, however, are wholly or partly contingent. This is often as bonds or stock — either preferred or common, or both. In other cases it is expressed as "payment out of the first oil." This is, of course, contingent, since there may be no first oil, or an insufficient amount.

(2) *To retain.* — A very large proportion of all developed properties were not drilled until after such a delay following leasing as to demand one or more payments of rental. This may happen because the operator takes up a large block of leases and drills a test well on one lease. If successful there, he ordinarily drills successive wells outward, one location at a time. By the time the first well is drilled on some of the outlying leases, there frequently has been such a delay that one or more rental payments are necessary.

Many leases are taken scattered throughout a large area, thought in general to have possibilities, in the hope that successful development near some of these will make them sufficiently promising for a well, or to appreciate the value of the lease so that it can be assigned at a profit. While it is not a sound method, it has been practiced a great deal. The result is to make a very heavy load of rental payments. Some of the leases are often dropped after a few such payments, if, in the meantime, the region has been inactive or has been condemned.

A similar type of leasing is to take up leases surrounding those held by a company which is drilling a "wildcat." While this has the disadvantage of a higher bonus, it has the advantage of few or no rental payments, since, in case of failure, the leases are often promptly dropped.

Rental payments have the effect of spreading out development, as an operator, to stop these payments, will, if the sacrifice is not too great, drill the first well on another adjoining lease rather than drill another well on the same lease. He is sometimes led to take too long a chance and so drills an unnecessary dry hole, although this results more frequently from drilling at the end of his term, when further rentals will no longer suffice to hold the lease.

The Indian lease in Oklahoma is peculiar in calling for a higher and higher rental with successive years, thus putting pressure to bear to drill prematurely — a pernicious practice operating against sound conservation.

(3) *To develop, if undeveloped.* — The investment necessary to develop a property must be estimated by comparing it with analogous properties and by considering the fluctuation of the unit costs. In a new region, this is difficult until after the first well has been drilled, when the principal items — price per foot to drill and the amount and size of casing and tubing required and its transportation — may be reasonably well estimated. The dip should be known, especially if the property is in such fields as those in California, the Rocky Mountain states, or in the Coalgate-Poteau gas district in Oklahoma. Otherwise the producer cannot estimate, on account of varying depths, the cost of drilling other parts of the property.

If the country is very rocky, with steep topography, or if swampy or subject to floods, allowance must be made for the heavier costs of transportation and delays. The distance from the railroads, when more than ten miles, as in several of the Big Horn pools, is of vital importance. It has so far prevented the development of the otherwise promising San Juan field in Utah and had postponed the development of Grass Creek Basin many years.

The labor costs become unduly high in some foreign countries, where oil development is not yet established and skilled workers have to be imported. Indirectly, tropical diseases may greatly raise the labor costs, as in Colombia. Another cause of increased costs, sometimes not adequately allowed for, is remoteness from supply centers. Great expense is thereby caused by waiting for parts or supplies for repairs, or to overcome unforeseen contingencies, especially in fishing. Where there is no proper housing near the property, the expense of such construction for the men must be planned for.

The property may be wholly unsurveyed in a region without land corners, when provision must be made for extensive surveying. There is further the expense of a geological survey, frequently, but improperly, omitted, and especially important in regions of high dip.

In fact, there are so many expenditures, in addition to the usual ones, in foreign pioneering work, that it can seldom be successfully accomplished by any but large companies with ample resources.

(4) *To continue development when this is not complete.* — By development, the miner means the completion of workings which will demonstrate the existence of and make possible the removal of the ore. In oil production the term is used when all the wells are completed and made ready for operation. Properties are sometimes sold when one well has demonstrated a real value, plus a further speculative value. More frequently the sale takes place when the most promising part has been drilled, but there is a further part that may be worth drilling with probably less favorable results. This poorer result will arise partly because of natural inferiority and partly because by this time the diminished pressure has greatly reduced the extractibility of the oil and the wells have lost some oil to surrounding wells. Some properties are believed to be as fully developed as is possible, the undeveloped part being judged unproductive. Examination by the prospective purchaser may convince him that some of this undeveloped territory is worthy of test and it may in part prove to be so.

A property is sometimes bought while still flowing. It should not be considered fully developed, and allowance should be made for the money necessary to install a "power" and to make the change. Even when a property is pumping by separate engines supplied with steam from batteries of boilers, it is so likely that a central "power" should be installed or electric pumping instituted in certain contingencies, that the development may be considered incomplete and allowance should be made in the same way for this completion of the development. Proper plants for supplying water and gas or connection with lines which supply them must be provided in development.

(5) *To put into a satisfactory condition.* — A new management is very likely to find a lease unsatisfactorily equipped, even though it is already "on the power." For instance, the shackle lines may be badly slung by ropes where they cross ravines. There is, therefore, very frequently some excess expenditures over maintenance during the month or so after the transfer. These expenditures are development expenditures, and should be estimated and allowed for in the valuation.

(6) *To maintain.* — Maintenance should be divided into *regular*, *occasional* and *accidental*.

The calculation of the *regular maintenance* may be, in general, subdivided into *wages*, *supplies* and *transportation*, the rates of which may ordinarily be ascertained with little difficulty. It presents, however, a few characteristic features, depending upon the system employed.

To have the wells all completed and all still flowing on medium or large leases is uncommon, except where the sand is shallow. In the Delaware (Oklahoma) pool this condition was realized. The result is always amazingly low maintenance, because it is so nearly automatic. Whenever very low maintenance per well is reported, one may suspect that the property is flowing. Maintenance may be calculated per well-day, acre-day or per barrel. It is especially by this last method that flowing properties show such low maintenance. Brokers have sometimes improperly made use of this low maintenance in figuring profits for a lease. However, a deal could hardly be consummated before the heavy expense of pumping equipment would be necessary and maintenance be increased to the normal amount. It is important, then, to consider this low maintenance, while the wells are flowing, merely as a passing phase.

The maintenance varies with the method of pumping:

(*A*) Individual steam engines and boilers: The maintenance is highest with this method of furnishing power, so much so that, except for isolated wells, it is generally supplanted later. A relatively great amount of labor is required to tend all the scattered boilers, even though they burn gas.

(*B*) Individual gas engines or electric motors: Where the central power and shackle lines are infeasible, the lowest maintenance cost is secured by individual gas engines where gas is cheap or by electric motors in certain other contingencies — equipments which obviate many scattered boilers.

(*C*) Central power and shackle lines: The lowest permanent maintenance of any group of settled pumping wells is obtained by this means, except under certain limitations, *viz.:* (*a*) The necessity of retaining an engine at the well because of very frequent pulling or cleaning; (*b*) very great depth of wells; (*c*) great distance between wells; (*d*) great topographic difficulties; and (*e*) inabiliry to obtain the right to lay the shackle lines, as in town lot development or on very valuable land. These obstacles are more and more being overcome. When the Glenn pool was still flowing or was on individual engines, some thought it was too deep for "powers," yet "powers" are now used for much deeper wells and probably will be used for those still deeper. A "power" not infrequently handles all the wells, where not too deep, on a square 160-acre tract. One power in Northern Pennsylvania successfully handles 35 wells.

The occasional maintenance items are by no means negligible. These are least where the wells are cased to the top of the sand, or where the wells are in a hard sand which was well cleaned at first, with a liberal pocket drilled below the sand. In these circumstances only lubricating oil and the inevitable wear of cups (which would be relatively less) need be provided for. At the other extreme, we have wells that require so much cleaning and pulling to replace cups, because of the very soft running sand, that their maintenance is a serious item. In fields where such difficulties are regularly met, we find strainers of the proper mesh in use. These should also be used in a few areas in the fields which are, in general, hard sand fields, and more widely used in others where it is thought necessary to bail the oil, as in Russia. While the appraiser should ascertain how much cleaning and pulling have been necessary in the past on the property in question and also on the neighboring leases, it must be remembered how much this depends on the thoroughness of the cleaning after the shot, the presence of adequate pockets, the proper placing of the shot below the upper part of the sand, so as to avoid leaving only a shale roof to the shot hole, and the proper placing of the perforations below the working barrel. Good management in these points, treated in Chapters 13 and 14, very materially reduce maintenance cost.

Recently additional items of maintenance have appeared, and will continue to appear, as the art of obtaining the utmost amount of oil that is feasible from the sand receives the great attention it deserves. These methods are all in their infancy, and we may well expect that in the future we are to hear much of water flushing, pressure conservation, electric heating, etc. For the immediate present, however, the appraiser would better value the property without reference to the higher extraction in these ways, because, until there has been more experience, there might be extra experimental costs. This leaves these ventures, promising as they are, to be considered as separate investments. In a few years some of these devices will become so customary that they will be figured in the regular maintenance.

Accidental maintenance. — The hazards of the oil field are likely to be underestimated. The location of the property is a factor in estimating these hazards. The wind hazard, so important where the derrick is used and left standing, is greater in Kansas, in the northern tier of counties in Oklahoma and in southwestern Illinois, since tornadoes are most frequent here. The use of guys is far less of a protection than is supposed.

The fire hazard is greatest where the hot dry summers in untilled regions lead to prairie fires. This condition applies especially to the Osage Nation in Oklahoma. In such regions fire breaks should be ploughed around derricks and buildings. Sometimes early intentional burning may be desirable before the grass is too long or dry, but this, in itself, is, of course, dangerous and should only be attempted by experienced men. Such work, when carried out annually, as a regular practice, should be included in regular maintenance. Flood hazards are so local as not to be easily overlooked, but there are so many oil properties in river bottoms subject to flood that the situation needs to be understood. One otherwise valuable riverside property, in the Cimmarron River in the North Cushing pool, was abandoned by its operator, so great were his flood expenses.

The danger from lightning is notoriously high for oil tanks and derricks. The common belief that rising gas itself attracts lightning is questionable, but the height of the isolated derrick wet by the rain, and the iron of the tank offering so large a metallic surface, are quite enough to make this a hazard worth allowing for. Unfortunately, statistics are not available.

(7) *Taxes.* — The item of taxes upon oil and gas properties shares the large element of variation which is characteristic of this industry. This variation in taxes is to be attributed to the fact that no settled method has yet reached general acceptance, and that oil offers a shining mark to legislators, because its very speculative character gives a false appearance of very great average returns. Largely for the sake of stability, an *ad valorem* tax on production is desired, as the rate is less likely to fluctuate than one levied upon the physical property; and it varies more directly with the value of the property than a tax on equipment, which would be disproportionately high on old wells yielding very small profits. The proposal to tax prospective value as well as production has a certain plausibility. Yet the speculative element is so relatively high in undeveloped lands, and the price fluctuates to such a degree owing to the periodic discovery of market breaking pools, that it hardly seems feasible.

There is, in addition, the federal tax on corporations. This should be repealed, since the small corporation with little profit carries a burden not intended for it, because it bears a name that savors of wealth to the undiscriminating. The heavy fees levied by the states for incorporating, for engaging in business in states outside that of incorporation, and for enlarging the capitalization, are essentially taxes which add an appreciable item to costs in the companies organized specifically for one lease or for a few leases.

(8) *Share of general expenses.* — We include under this caption those expenses not specifically chargeable to either developing or operating

a property, unless it is the only one owned by the individual or company. Most properties are one of several leases, some of which are not contiguous, that must share several items of expense. These are especially those of the office, such as managing, accounting, legal, etc. Some of the transportation not easily divided among the properties may be charged here. This burden is very high when the leases are all small and considerably scattered, as is so common in the Cherokee Nation, Oklahoma. The contiguity of leases is a very important element, both in maintenance as well as in the matter of general expense. One superintendent can perform the services of several where the property is compact. The large size of the properties in the Osage has been advantageous in this respect. This, with the absence of rentals there, has served in part to compensate for the heavier burden of royalty.

It is not safe to assume that the general expenses under a new management will be the same as those under the old. The number of properties that will divide the expenses will probably be different. Again, it may be possible to eliminate some unnecessary expense. On other occasions, the property may have been operating under a staff inadequate in quantity or quality, so that increased expenses will be necessary. It is very important to figure what the costs will be. What they have been is, of course, the principal guide, but by no means the only one, in deciding what they will be in the future.

Income

In dealing with outlay, the uncertainties have not been much greater than in other industries, and the methods of determining the costs have not been very different from what one might find in some other industries; but in considering the income of oil and gas properties, we are dealing with an unique situation that is worthy of extensive analysis. The income factors may be classified as follows:

(I) Terms of the holding.
(II) The amount of production and its distribution in time.
(III) Agencies which may interfere with a normal production.
(IV) Possible improvements in methods during the life of the lease.

(I) *Terms of the holding.* — In estimating the revenue one first ascertains whether the company receives all the product, or the product less a given percentage, as in royalty, or less a fixed sum (as is still quite common for gas). This has a double importance, first, because of the deduction itself, and second, because the length of the working life of the well depends in large part upon the size of the deduction.[1] The higher the royalty, the earlier abandonment is forced, and thus less production is obtained. Royalty might be considered as expenditure; but since the purchasing company usually, by means of a division order, transmits the lessor's share to him direct, it is better not to count it into receipts, and hence not into expenditures, and so much accounting is saved.

In cases of leases which do not run "as long as the oil and gas is found in paying quantities," as in minor leases or Osage leases, one must ascertain the following three elements, if there is reason to believe there will still be paying wells on the lease at the time of expiration: First, the gross profit received up to the expiration of the lease; second, the price to be received for such movable property on the lease as may be sold or that may be removed to other properties if the lease is not renewed; third, if renewal is doubtful, the chances of success in getting it renewed; and, fourth, if renewed, the value of the renewal. This renewal value is the productive value after renewal less the consideration forced for the renewal. This consideration is ordinarily less than the productive value, because the wells are likely to be old and the operator who has the lease can ordinarily obtain more from them because of his knowledge of the wells than could an outsider. There is also the threat to "pull" some of the wells that are near enough abandonment so that the land owner would have difficulty in preventing it.

(II) *Amount of production and its distribution in time.* — The estimate in advance of the amount of oil or gas to be produced is the crux of valuation. The amount of oil to be obtained is the result of two sets of factors: (*A*) those determining the amount of oil or gas underlying the property, (*B*) the proportion of this oil and gas in the sands that are exploited; and (*C*) those determining the percentage of this which can be produced.

(*A*) The amount of oil or gas underlying the property depends upon the following considerations, for each of the sands, if there are more than one:

(1) The capacity per unit volume of the reservoir. This is by no means the porosity, as frequently stated, for some pores are so entirely surrounded by grains or cement that their contents could not escape. Furthermore, a high degree of porosity is of no avail if the pores are so small that adhesion and "capillary drag" prevent the fluid contents, at the given pressure, from escaping at a sufficiently rapid rate to make a

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[1] Johnson, Roswell H., "Sliding Royalties for Oil and Gas Wells," Bull. Am. Min. Eng., 102, pp. 1291–1294.

paying well. Determinations of mere porosity, then, are relatively valueless. The determination of value to the oil producer is that of the amount of fluid that can be taken out of a given rock — its yield. No satisfactory laboratory method has yet been devised by which the yield of a small piece of sandstone can be determined. The nearest approximations are as follows:

(*a*) Its *oil content*, which is determined by grinding (if consolidated) and extracting by solvents. The difficulties are: (*i*) this includes some oil that cannot leave the pores naturally; (*ii*) the sample is at atmospheric pressure and gives a different oil content from that which it had *in situ* at the natural pressure, particularly owing to the formation of gas bubbles from what was dissolved gas when the pressure was relieved; and (*iii*) in case the sand is unconsolidated, its content changes as the interrelationship of the grains is disturbed in being removed.

(*b*) Its *reception capacity*, which is best measured by an adaptation of Buckley's method[1] of determining specific gravity, porosity and absorption of building stones. The sample is rid of any possible oil content by treatment with "petroleum ether," this solvent being forced in and out by change of pressure. After being thoroughly dried at 110° C., and no higher, so that no chemical changes are produced, it is again treated with petroleum ether and again dried. After weighing, it is placed in a bottle, and a standard oil free from gasoline, such as claroline, is introduced at the bottom, as the air content is exhausted from the rock by a reduction of the pressure in the bottle. The samples remain in the bottle at $\frac{1}{12}$ atmosphere for 36 hours, after which the pressure is slowly raised to that of the room. The amount of oil imbibed can now be determined by weighing at a standard temperature, after removing the surplus oil with bibulous paper. Cold oil is used instead of hot water, as in Buckley's determination, not only because it is more analogous to petroleum, but also to eliminate evaporation during weighing and to avoid dissolving any of the sandstone, in which the cement especially may consist partly of soluble minerals.

Capacity, thus determined, is not the yield because capillary drag and adhesion render the yield much smaller. "Reception capacity" and yield would, however, be highly enough correlated to make "reception capacity" the most valuable laboratory determination.

Any method based on samples has two great inherent difficulties:

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[1] Wisconsin Geol. and Nat. Hist. Survey, Bull. No. 4, Econ. Series No. 2, pp. 63–69.

first, to get a representative sample, since a piece blown from a well has an uncertain origin and shows nothing as to the variation; second, to know what allowance to make for the difference between the laboratory conditions and those in the reservoir. Laboratory determination from samples is therefore uncalled for except in very novel conditions where the next method is unavailable.

(*c*) *The comparative production* figures from adjoining leases are used; or lacking these, available data from leases that seem to be the most similar in the most essential features to that of the property in question. Eventually, we may hope that a great deal of such data will be available to all. For California we have the excellent data expressed in a useful way in McLaughlin's "Petroleum Industry in California,"[1] and in Lombardi's "Valuation of Oil Lands and Properties."[2] May we not look to the Federal Bureau of Mines to publish decline curves of individual wells and properties in all important pools in all the sands of the country? In the meantime, reliance must be had on what data of this sort can be preserved and exchanged by individuals.

The greatest aid in such comparisons is the construction of decline curves and the calculation of decline rates. The attention of the oil producer to these graphic methods, which are very clearly presented in Brinton's "Graphic Methods of Presenting Facts," would be amply rewarded, not only in this connection but many others in the field of oil and gas production.

(2) *The size of the oil or gas deposit tributary to the well studied.* — This depends upon:

(*a*) Thickness of the reservoir.

(*b*) The part thereof occupied by oil rather than water or gas; or, in gas properties, that part occupied by gas rather than by liquid.

(*c*) The distance of the neighboring wells or of the boundaries of the reservoir.

(3) *The extractability of the oil and gas in the sand.* — This may be neglected in the case of gas, for, by the use of vacuum pumps, the extractability of gas is very high. Moreover, gas is extractable from sand of lower porosity than is oil. Since ordinarily the contact between adequately yielding sand and inadequately yielding shale is a transitional one, it follows that a given reservoir is smaller as an oil reservoir than it is as a gas reservoir. An additional amount of gas is given up from solution in oil, if there is oil in the same reservoir, as the pressure

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[1] Bulletin 69, California State Mining Bureau.

[2] West. Eng., Vol. 6, p. 153.

goes down. If there are wells in another part of the reservoir, where the upper part contains gas and the lower or middle part oil, of course a great deal of gas is lost to the property being valued, but the amount varies according as the other operators are provided with separators or use their casing head gas, and if so at what pressures.

The extractabilty of oil depends upon:

(*a*) The initial pressure of the reservoir.

(*b*) The presence of a considerable amount of gas in the same reservoir, either in solution or free.

(*c*) The rapidity with which the oil, and more especially the gas, is being exhausted by the completion of other wells in the same reservoir.

(*d*) The dip of the reservoir.

(*e*) The viscosity of the oil at the reservoir temperature.

(*f*) The encroachment of water.

(*g*) The nature of the sand.

(*a*) *The initial pressure.* — The general belief that deep sands "hold up better" than shallow sands is one result of the important rôle played by pressure, since pressure ordinarily increases with depth. The natural impression that oil flows into the hole merely as a result of gravitation is difficult to overcome. Yet as the passageways in a series of sands become increasingly small, adhesion and capillary drag become so great that the oil no longer flows into the well at a paying rate when the pressure falls to a certain point. In most of the consolidated sands of the Appalachian, Lima-Indiana, Illinois and Mid-Continent fields, the pressure factor is quite the predominant one as compared with gravity. If a piece of ordinary oil-filled sandstone is laid upon a plate, it is surprising how little of its oil runs out. The production of a well declines step by step with the reduction of pressure, and where the sandstone is consolidated and not very porous, the well ceases to have a commercial production before the pressure has been reduced to that of the air in the hole. A high pressure then leads one to expect a much larger and longer production.

(*b*) *The presence of gas.* — Since liquids are so slightly compressible, the expulsion of oil into the hole is mainly dependent upon the expansion of the gas-filled portion of the reservoir from its own natural expansion and the yielding up of dissolved gas from the oil as the pressure declines. Moreover, this gas is not all contributed to the gas-filled portion of the sand, but some of it develops gas bubble nuclei in the several larger pores. It is by virtue of these that the oil is able to leave relatively fine grained reservoirs; otherwise it would be impossible. In illustration, a cube of sandstone filled with carbonated water yields more water for this reason than one filled with pure water.

(c) *Relation to other wells.* — A quick decline of the pressure greatly reduces its effectiveness for expulsion. The close proximity of many other wells, therefore, reduces the value of a well, in addition to the effect of proximity in reducing the size of the contributing area. For this reason, a large lease, or a lease alongside a property not drilled because of litigation or other difficulties, is worth more per acre than a small one. Properties in a region where line wells are by custom drilled farther back are thus more valuable. The productive value of very small leases is so much greater if combined with those of a neighboring lease owner, that an effort should always be made to reach an equitable basis for sale, purchase or trading, in order that the superfluous wells may be eliminated. In spite of the obviousness of this situation, the ridiculous sight of town-lot crowding is seen nearly always when production is found where the land ownership is thus parceled, although experience has so often demonstrated that such operations are losses in an overwhelming percentage of cases. The last instance, that of Evans City in 1915, was as bad as usual. Irregularity of outline makes the protection of a lease so expensive that it pays much better to sacrifice some of it to a neighbor's offsetting well. The senior author once recommended the sale of a nearly cross-shaped lease, owing to this consideration, and the price received was a good one, since the defect failed to impress the undiscriminating purchasers.

(d) *Dip of the reservoir.* — Properties high up the dip, where the dip is considerable, 100 feet to the mile or more, and where the porosity of the sand is high, suffer in value by reason of the loss of their oil to the lower leases as the oil is withdrawn from the latter. By the same reasoning, the value of the lower properties is enhanced by the replacement of the oil withdrawn by that from above. This principle must not be pushed too far, for, in sands of low porosity, gravitation plays too small a rôle.

(e) *The quality of the oil.* — The higher viscosity of very heavy oils reduces their "extractability." But the difference is lessened owing to the fact that for about every 60 feet in depth there is an average rise in temperature of about 1° F. though this is quite variable. The warmer temperature of the oil in the sand greatly reduces viscosity. In high-pressure consolidated sands Quick[1] believes there is refrigeration, caused by the sudden reduction of pressure at the sand face, a condition which may in some degree counteract this higher temperature. He contends that such refrigeration in the case of high paraffin oils seriously reduces the flow by clogging the sand face.

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[1] Quick, Miles W., Nat. Petrol. News, Vol. 5, pp. 1–4, and following issues.

(*f*) *The encroachment of water.* — When a pool has encroaching water, all properties down the dip have their value reduced, because of the liability to a shorter life from this cause. Those high on the dip have their value enhanced, because new oil is brought up as they exhaust the original charge. Unfortunately, it is difficult to foresee encroachment, so that allowance for it is in general restricted to the period after it has made itself felt in the lower part of the pool.

(*g*) *The nature of the sand.* — The texture of the sand is of supreme importance. A very fine sand or a shaly sand might have the same volume of voids and the same oil content, but necessarily has low extractability. If the sand texture is very uneven, small volumes of very porous sand being distributed in a finer matrix, the extractability is reduced, for only communicating systems reaching the hole are available.

A very common error in determining sand texture is to judge of it by the grains of sand after these are broken apart. The uniformity of the sand grains is more important than their size above a certain critical diameter. A still more important feature is the amount of cement between the grains. Roundedness, the high percentage of quartz grains and the size of grains are all more important, because these qualities are correlated in some degree with a lesser amount of cement, than on their own account.

(3) *Agencies which may interfere with a normal production.* — The career of many oil properties is a checkered one, quite aside from the accidental features mentioned earlier. While it is true that, in general, marketing is quite serene for the producer, since his sales are so nearly automatic, nevertheless there are certain disturbances. Pipe lines are broken at times, more especially by floods, which may shut down production for several days. In the winter time, the greater viscosity of many oils reduces the runs. On other leases some of this oil is "cut" (emulsified), so that it must be treated at some expense or loss, or in some cases burned; but fortunately this condition usually passes as pressure naturally declines.

Most important, however, are the "gluts" to which the petroleum industry is especially liable, owing to the suddenness with which new promising pools are developed. The pipe-line companies ordinarily do not lay a line to a pool at a distance from its established lines until the pool has demonstrated its importance. Not only do the runs from the new pool suffer, but also those from many other properties contributory to the same lines, since the runs are cut down to a given fraction of the whole production. This very seriously disturbs the income of the properties. While much of the oil production is simply postponed for later pumping, some oil becomes "inextractable" owing to the greater pressure loss in proportion to the oil raised. Caution is necessary in accepting Oklahoma and California decline curves without correction, lest they include such a period of over-production, with a decline curve artifically flattened.

(4) *Possible improvements in methods during life of the lease.* — In this day of enhanced interest in methods of higher extraction,[1] we may expect from among the numerous suggestions of pressure conservation, water-flushing, Marietta plan of utilizing compressed air, electric heating, over-deepening, etc., some decided improvements of efficiency within the next few years.

(5) *The price of oil and gas during the life of the lease.* — There is a great range in price for the different qualities of oil. If the lease produces an oil much better than the general field as at Cushing, inquiry should be made as to the possibility of shipping by tank car to some refinery competing with the regular purchasers of the oil. If the property is large enough, consideration should be given to the erection of a refinery by the operator of the lease to obtain the benefit of the better quality.

If the oil is ranked lower than the general grade, a similar procedure is indicated. The Wann, Oklahoma, oil was bought as an inferior grade at a lower price until a company for the manufacture of roofing paper and asphalt was established and built a pipe line to it.

Few minerals suffer the violent fluctuations in price that crude oil does. Oklahoma crude rose from \$0.35 to \$1.05 in $3\frac{7}{12}$ years, and then declined to \$0.40 in one year because of the Cushing pool. Even Pennsylvania oil, far removed as it is, was forced solely by the over-production at Cushing during the same year down from \$2.50 to \$1.35. With such fluctuations in income, which affect expenditures relatively slightly, the valuation of properties necessarily fluctuates violently. The efficient appraiser must, therefore, understand the various elements which affect the future course of the price. He should, if for no other reason, therefore, be familiar with the geology of the various fields and the nature and stage of development of the more important pools. A great amount of significant information is readily carried for the appraiser's use by keeping graphs from month to month.[1] These graphs should include the number of new wells, the amount of new production, the amount of total production, the average size of new wells, the percentage of dry holes and the stocks and prices for each of the several great fields. In addition, the appraiser watches for the significant, determining, dry holes or poor wells around the large developing pools. Probably the greatest fault of the inexperienced is to over-estimate the probable size of the pool opened by each new discovery; witness the Paden and Holdenville strikes in Oklahoma in 1915. Consumption is increasing so rapidly that many new pools are required to satisfy the demand, and only a very small percentage of the new pools are of market-breaking size.

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[1] Huntley, L. G., U. S. Bureau of Mines, Technical paper 51.

The stage of progress in the methods of the petroleum industry is a factor of importance. There is a rapid extension at present of geological work in prospecting, so that the rise in price, which recently set in with the decline of the Cushing pool, will probably be arrested by the increased efficiency of the drilling campaign that is now starting. On the other hand, after a while the number of successes will be fewer and fewer as promising areas are exploited. This condition will force another series of advances in price. While, in general, the efficiency of the appraiser depends upon his knowledge of the conditions in his own field, to foresee price changes, he must have the widest and most profound knowledge of many oil fields.

The Method of Valuation

After the appraiser has shown the varying elements in the income and in the outlay, he still has to calculate the surplus of income. But, unfortunately, wells being so soon exhausted, he has the two complications to consider, the realizable value from junk (as the casing, machinery, etc., is called) and amortization.[2] The junk differs very much in its value, depending upon whether it must be sold to dealers, or sold at better terms to a neighboring lease, or used on another property belonging to the same owners, with or without an intervening variable expense for transportation, storage and the depreciation incidental thereto. This gives an advantage to the large company.

For a good discussion of amortization in allied industries, the reader is referred to Hoover's "Principles of Mining" and Chapman's "Forest

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[1] Wolff, J. H. G., "California Petroleum and the European War," West. Eng., Vol. 6, pp. 166–168, gives an interesting example. See also "Report of the Joint Committee on Graphic Methods," Bull. Am. Inst. Min. Eng., 106, pp. ix-xii.

[2] Forstner, Wm., Valuation of Oil Lands. Min. and Sci. Press, Vol. 103, p. 578.

Valuation." Hoover thus speaks of amortization: "A portion of the annual earnings must be set aside in such a manner that when the mine is exhausted the original investment will have been restored," yet he admits later "in the practical conduct of mines and mining companies, sinking funds for amortization are never established." The principal differences between the amortization of an oil property and that of a mine are as follows:

(1) The income of the oil property regularly declines, while that of a mine does not necessarily do so.

(2) Owing to this, a successful oil property yields ordinarily in three years or so its cost, and pays thereafter a slowly diminishing profit.

(3) The average oil company owns several oil properties, and develops and buys new ones as the old ones are exhausted.

(4) The average oil company carries for a period many leases, representing a considerable outlay in bonus, rentals, etc., which are dropped without drilling. To this, in many cases, is added the cost of a dry hole, or a contribution to a joint test that is unsuccessful, before the lease is dropped. The successful properties have a heavy burden of unsuccessful ones to carry.

For the four reasons given, many oil companies are inclined to accomplish amortization in a different way which seems well adapted to the oil business. All the income from each property is devoted to paying the "debt of the property to the company" until it is "on velvet," when that property is for the first time considered a profit yielder. This method is illustrated by the following account form of the Sagamore Oil & Gas Company of Bartlesville, Okla., when under the management of W. H. Johnson. This was kept separately for each producing lease of the company. The main advantages of this method are that the situation is more easily grasped by the manager and directors, inefficiently managed properties are more easily detected, and, most important, the data is in convenient form for the valuation of the property, so that the relation of the exchange value to productive value is more evident. In this way the desirability of selling a property or of buying adjoining properties is easily indicated.

Production for month, barrels of oil.	Price of oil for month.	Income from production.	Income to date.	Outlay in excess of income to date.	Income in excess of outlay to date.	Net daily average production for month, barrels of oil.	Maintenance cost per barrel for the month.	Remarks.

A short cut in appraising is very common in the oil fields, *viz.*, the barrel-day, an amount for each barrel per day produced by a property. This method is very dangerous and can only be depended upon for inside properties in large pools where the several properties are very similar and of about the same age. An appraisement for one property, worked out laboriously, might then be utilized for another property by this method. The reason why the method is essentially unsound is that first, the decline curve is not a straight line, but one where the rate of decline itself gradually declines. Again, the maintenance is assumed by this method to be a constant per barrel, whereas it gradually increases. The method assumes that the loss in valuation is just equal to the profits, which is not true. The barrel-day method implies that the age of the property is a negligible factor. However, if we plot the true valuation for each year by barrels per day, it gives us a curve ascending during the early life of the well, because the decline rate is less each successive year. After about the fourth year, in some properties in Oklahoma, the barrel-day value gradually declines, because the growing maintenance per barrel becomes so important a factor. One may say that in buying properties where the sellers are influenced by the barrel-day figures, it is best to buy an ordinary Oklahoma property in the third to fifth year, and best to sell when the property is either young or old; but not in that very late period when wells are worth more as junk than as producers. This time curve of valuation by the barrel-day ought to be worked out, for a typical property at least, in the field where the appraiser works.

While one should not base his ideas of productive value on the current quotation of production in terms of barrel-days, he should learn all the sales possible in these terms, so he can study exchange values, and thus take advantage of discrepancies between them and productive values.

There are two common errors as to the time of "settling." It is more variable and is later than generally supposed. The settling of a discovery well depends principally upon the time taken to drill the adjoining locations. Settling is that stage in the history of a well when there is the greatest change in the transition of the rapid rate of decline to the slow rate. In wells drilled where the data is kept by weeks or months the author has found settling in several cases between 12 and 24 months. Since settling is later than is commonly supposed, a favorable time to sell is at the end of six months, while the well is really not yet settled, although it is believed to be so by many producers. On the other hand, when purchasing properties, where quotations are made on a barrel-day basis, it is much safer to buy after the wells have produced for two years.

It is very important to appraise developed and undeveloped portions of a property separately and then to add the appraisements. All too commonly the undeveloped territory is used as a vague bonus to smooth over uncertainties in the valuation of the developed portion. The appraisement of undeveloped territory rests on (1) what this territory will be worth if it is normally productive under the given conditions; (2) what are the chances expressed in percentage that this property will be productive; and (3) since there is a considerable risk, what insurance for risk shall be figured in. Factor (1) calls for the same work as developed property, while (2) is primarily a problem for the geologist, although he will be greatly aided by the graphic device by which the proximity value is calculated.[1]

The risk element is extremely important. A very large company undergoing many risks should consider this element as nearly negligible; whereas the individual operator of small capital ought to put it quite high. It would be much better for him, unless he has unusual ability or information, to put his money with others in a large company, or into an "Oliver plan" company,[2] *i.e.*, a government promoted company to operate on some favorable structure on the public lands.

The appraiser must consider the use to which his valuation will be put. If he is to appraise for taxation, the exchange value should be approximated as closely as possible. If it is for the purpose of inventory or as a basis for a merger, its productive value will be approximated. But when for the purpose of buying or selling, he must be concerned with both exchange and productive values. He gives greater relative weight to exchange value if he represents a company that deals in properties.

If one is fixing a price at which to sell, he uses the higher of these two values. If one is fixing a price at which to buy, he must also ascertain the productive value and exchange value, and place the price at the lower of these two values.

But a better policy is for the appraiser to know at all times whether exchange values are running higher or lower than productive values on the several types of properties, and then become a buyer or seller of that type, the exchange value of which deviates most from the productive value.

Productive value obviously varies with the degree of efficiency of the future management of the property. Insofar as this can be foreseen, it will be used by the appraiser. The productive value is not a fixed attribute of a property, but in the nature of a prophecy. It follows then that the buyer for a company that is in a position to get a greater profit from a property, would properly place a higher valuation upon it. This brings us again to a consideration of the relative efficiency of small and large producing companies, and of companies engaged solely in production and those that integrate the several steps in the industry.[1]

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[1] Johnson, Roswell H., in Petroleum and Natural Gas Resources of Canada, Mines Branch, No. 291, Vol. 1, pp. 325–326.

[2] Hearing on H. R. 16,136, Com. on Public Lands, U. S. Senate, 63rd Congress, 3rd Session, pp. 171–173.

There remain the obvious differences between the company that has a property already adjoining that in question, with one having a property in the same pool, and with one having none in the region. This difference is so very important that it should be the policy not to take anything less than 80 acres under ordinary circumstances, in the Eastern or Mid-Continent Fields.

In Lombardi's method[2] the cost of drilling the undrilled portion of the lease is distributed through the years at a rate so regulated as to produce a uniform profit. It is so rare that such a procedure is possible and desirable that it is best in general to charge the costs of drilling to investment rather than expense, especially as most companies have several leases, for each of which a separate valuation is desirable.

It is not at all important that the income from each lease should be kept uniform. An oil company does well to try to keep its income steady merely through the ownership of many properties in various stages of development. Each property should be managed mainly with reference to its own maximum efficiency. Some leases in pools where the pressure is rapidly declining should be rushed to completion. In other cases where the pool is entirely within the company's lines, the development should be planned as a careful "feeling out," so as to drill a minimum number of dry holes. In this last case, if there is over-production, the whole property should be held back, even though dividends suffer for the time.

On the other hand, if we appraise a large company made up of many leases, we may properly make deductions from a sum of the values of the properties because of economies already indicated.

There are some large companies which for their highest efficiency demand a regular production, because of a selling contract or because allied with a refinery. This regular production is in contrast to the shrinking production of a single lease. In valuing such a group of

[1] See page 196.

[2] West. Eng., Vol. 6, p. 153.

properties we have an additional factor — the cost of maintaining this production at the given level. Lombardi has ably discussed this problem[1] with reference to California.

This is quite difficult because it involves either the continual purchase or the "carrying" of undeveloped land with all its uncertainties. So far as the cost of the drilling campaign is concerned, there are three different approaches which should be used as checks against each other, as follows:

(1) Experience of other companies. If the most analogous company keeps three "strings" at work, and they fail to prevent a decline in production by an ascertained amount, the number that would be necessary for a given production can be calculated.

(2) The total number of wells drilled in the whole pool compared with the increase they produce, or the decrease that results in spite of these new completions.

(3) Calculation from theoretical decline curves of the number of new wells necessary, counting in an estimated percentage of failures.

In conclusion, the appraiser should beware of his principal danger, that of underestimating the differences between properties in different sands, pools and regions. The constant keeping and elaboration of data on properties in a great variety of conditions can alone save him from too far-fetched comparisons.

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[1] Bull. Am. Inst. Min. Eng., Sept., 1915, p. 2109.

CHAPTER XXII

THE OIL AND GAS FIELDS OF NORTH AMERICA

It is the purpose of this chapter to divide the oil and gas fields of North America into natural fields in so far as may be possible. Most of these units are briefly treated as to the following points:

(1) Limits.
(2) The production — past and present.
(3) The location of the pools or prospects.
(4) The geological section.
(5) The texture and horizon of the sands.
(6) The attitude of the beds, and depths of wells.
(7) Prospects of future development, both as to formations and localities.
(8) Grades of oil.

A selection will be given of the most important articles on each field. Only those areas (Fig. 92) are discussed which at this time are important enough in their production or prospects to be worthy of attention in a treatment of this scope. It is by no means to be understood that the rest of the continent is without promise of production, or that there are not a few scattering "shows" of oil and asphalt outside these areas. However, we may safely consider the Archean and Algonkian area, shaded in Fig. 91, as hopeless. The fields will be considered in geographical order, as follows:

(1) Mackenzie River.
(2) Patricia.
(3) Northwestern Plains.
(4) Canadian Foot Hills.
(5) New Brunswick and Quebec.
(6) Erie (including Ontario in Canada).
(7) Appalachian.
(8) Michigan.
(9) Lima-Indiana.
(10) Illinois.
(11) Mid-Continent.
(12) South Mid-Continent.
(13) Gulf Cretaceous.
(14) Gulf Coast.
(15) Black Hills.
(16) Wyoming.
(17) Front Range.
(18) Pecos.
(19) Rocky Mountain Interior
(20) Snake River.
(21) Alaska.
(22) Coast Range.
(23) San Joaquin.
(24) Southern California.
(25) Vera Cruz-Tamaulipas, Mexico.
(26) Tehuantepec, Mexico.

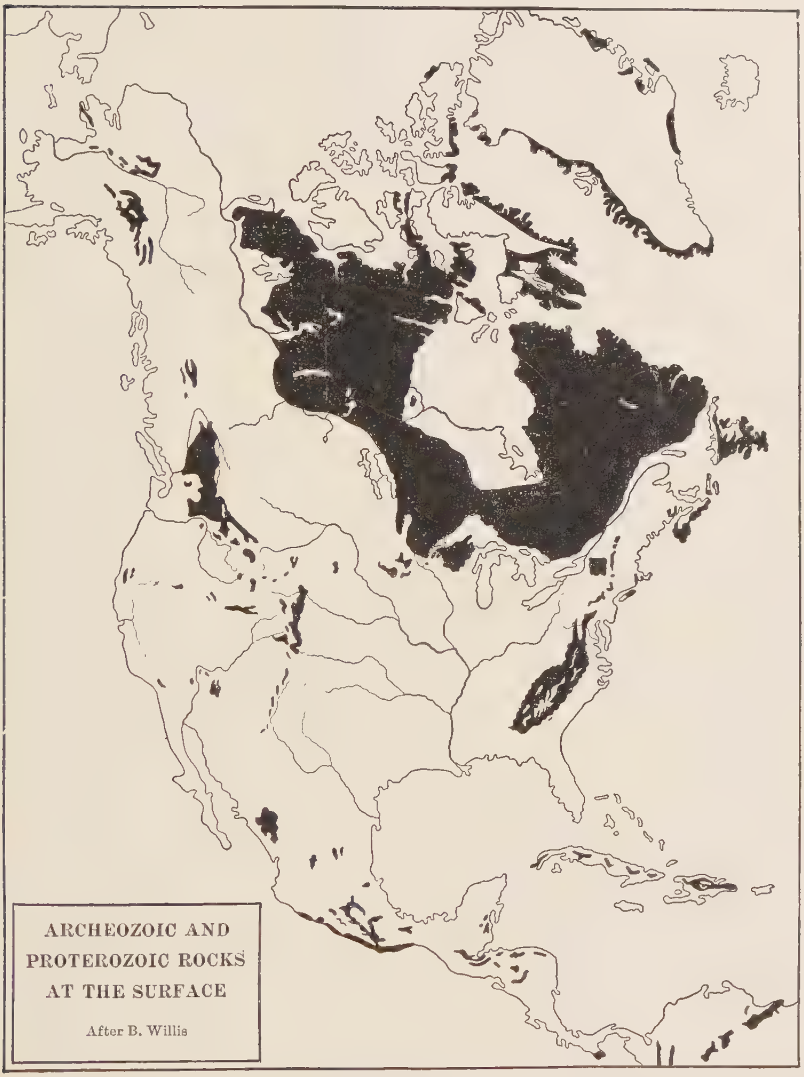

FIG. 91. Showing some areas in black where oil and gas prospecting is useless.

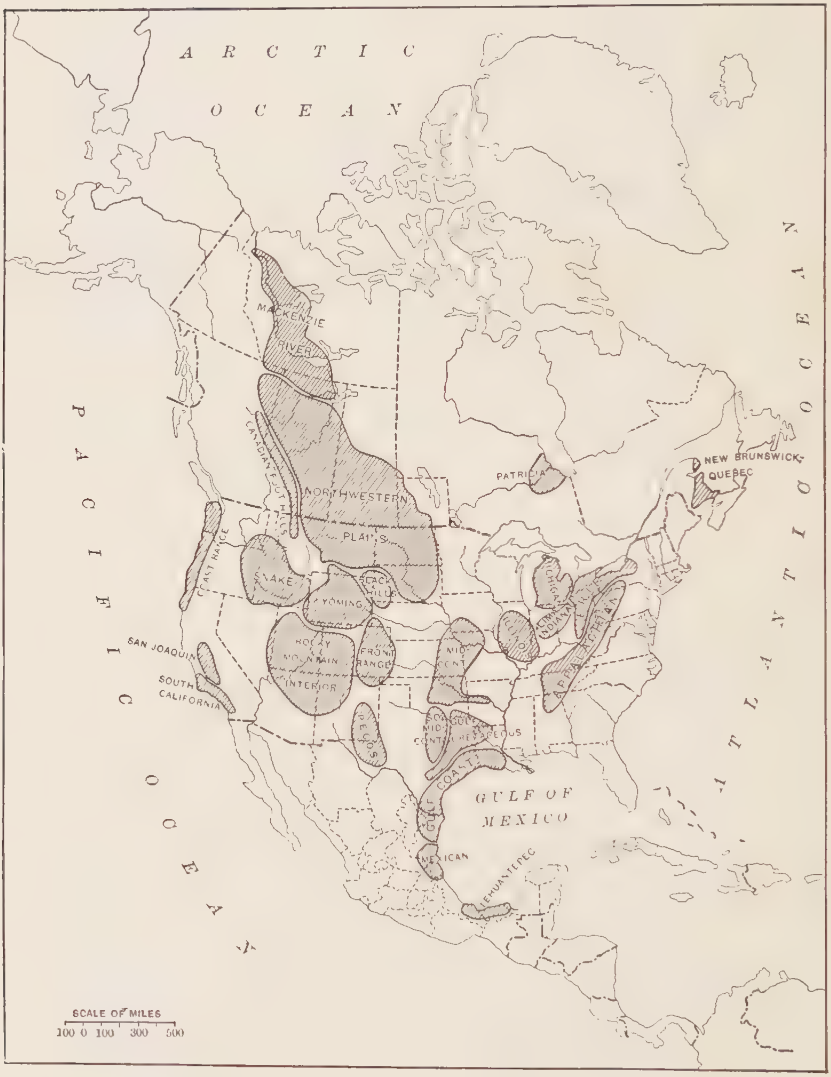

FIG. 92. The North American Oil and Gas Fields.

In addition to the productive fields, a few prospective fields have been recognized because they have been thought important enough to have given rise to a literature. The Canadian fields have been systematically described in "Petroleum and Natural Gas Resources of Canada," Vol. II, Mines Branch Department of Mines. There are a few occurrences of oil or gas shows outside the fields named. These have been listed for Canada and the United States.[1]

Mackenzie River

The Mackenzie River field may be said to comprise within its limits the district west of the Slave River and north of the Peace River, and extends on both sides of the Mackenzie River from Great Slave Lake north to The Ramparts.

There has been no commercial production from this area up to the present time (1915). Asphalt from seepages has been used by the Indians for various purposes, but no wells have been drilled within the limits of this district, although English interests have had reconnaissance parties in the field during 1914 and 1915.

The numerous springs and seepages which occur on the shores of the western limb of Great Slave Lake have been described by McConnell[2] and others,[3] who also describe other well-marked occurrences of bitumen-saturated limestones and shales at the following localities along the Mackenzie River.

	Latitude
1. Rock by the River Side	63 deg. 20 min. North
2. Bear Rock	66 deg. 10 min. North
3. Fort Good Hope	66 deg. 15 min. North
4. Old Fort Good Hope	67 deg. 30 min. North

This entire district is covered by rocks of Devonian age, with a few remnants of Cretaceous and Tertiary sands and shales. The Devonian beds are those which appear promising for the development of oil production, and regarding them McConnell states that the lithological character and stratigraphic relations of the limestones and shales on the Hay River section, 40 miles above its mouth, and of The Ramparts on the Mackenzie, are almost identical. The same holds true for the fossil fauna, although these two sections are 570 miles apart. Since that time wells drilled through the Devonian formations on the Athabasca River show that this similarity extends much farther to the south, and so indicate the same general horizon to be petroliferous throughout its extent of at least 920 miles.

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[1] Sanford and Stone, Useful Minerals of the United States, U. S. G. S. Bull. 585; Johnston, R. A. A., A List of Canadian Mineral Occurrences, Can. Geol. Survey, Mem. 74.

[2] McConnell, R. G., Can. Geol. Surv. Summary Rept., 1890–91, Pt. D.

[3] Bosworth, T. O., Petroleum World, Feb., 1915.

Throughout the district, the Devonian is generally divisible lithologically into an upper and a lower limestone separated by varying thicknesses of shales and shaly limestone; but in some cases limestones occur throughout. The upper division is approximately 300 feet thick, of compact limestone which weathers yellow, and is occasionally composed of corals, with some dolomitic beds, which are underlain by several hundred feet of greenish and bluish shale alternating with thin limestone beds. This shaly series is sometimes hard and fissile, and blackened by bituminous material. At Bear Rock this shaly series is interbedded with gypsum, which sometimes almost entirely replaces the shale. Thick beds of salt and gypsum have been found at the same horizon in wells drilled in these formations at Fort McKay, Fort McMurray and Pelican Rapids on the Athabasca River. At all places it is this shaly series which is petroliferous. The accompanying sections (Fig. 93) are those of wells drilled south of Lake Athabasca, corresponding closely with McConnell's description of the more northernly exposures of the same formations.

The beds are nearly horizontal at all points within this area below the mouth of the Liard River. Northwest of the mouth of the Liard, the Mackenzie enters the Rocky Mountains, and thence north to The Ramparts the structure is broken by several pronounced anticlines. .In view of the uniformity of conditions in this middle shale-salt-gypsum series, it is quite probable that on favorable structures productive reservoirs of oil will be found. The quality of oil found in seepages varies from that of a light gravity to thick asphaltum, but such occurrences cannot be considered criteria of what drilling may disclose back from the outcrop.

The feature which may cause the reservoirs of petroleum to be somewhat erratic and relatively independent of structure is the scarcity of sandy strata. The fissile character of the shale beds, and the presence of oil in dolomitic limestone or saline or gypsiferous beds is likely to cause irregular reservoirs, and hence prospecting is more difficult.

District of Patricia

Wilson[1] reports the existence of outcrops of bituminous limestone in the vicinity of the Abitibi River, in the District of Patricia, bordering

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[1] Report on the District of Patricia, Ontario Bureau of Mines, 1912.

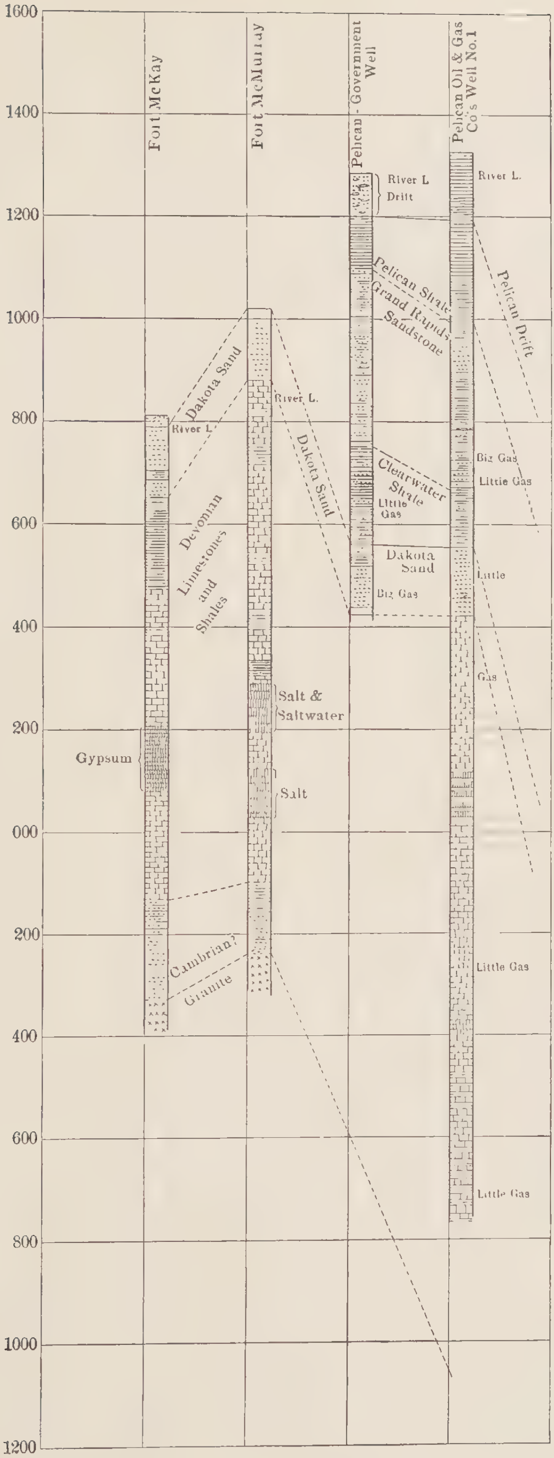

FIG. 93. Logs of wells drilled along the Athabasca River into Devonian strata.

James Bay on the west. No promising reservoirs are assured, as the beds are relatively thin and eroded, being composed principally of limestone (Devonian and Silurian) underlain by granite.

Although the transportation facilities are at present bad, a railroad is in course of construction, which will connect with the main lines. The character of the formations and lack of well-marked structure offer so little chance of developing any extensive pools of oil or gas that little encouragement can be held out to the prospector.

Northwestern Plains

The Northwestern Plains field includes that area of gently dipping beds lying east of the Canadian foothills, and north and northeast of the Big Horn and Black Hills uplifts in the United States. It is here considered separately from the highly folded foothills belt in Canada, not only for structural and stratigraphic reasons, but also on account of its different historical development.

No oil production has as yet (1915) been developed in this area in commercial quantities, although what are probably the world's greatest seepages of bituminous and asphaltic material exist in the famous "tar sands" (Fig. 94) on the Athabasca River and its northern tributaries. McConnell[1] estimates that these asphaltic sands underlie an area of at least 1000 square miles in extent, and more recent explorations have given evidence that the area is even greater than this. Many claims have been "denounced" along the Athabasca River for working these deposits, some of which have been abandoned. But until the railroad now building to Fort McMurray penetrates this district, the difficulties of transportation will prevent the profitable exploitation of these deposits. Several shallow wells have been drilled into these "tar sands" a few miles north of Fort McKay, at a point where a low synclinal fold has depressed them below the river level, and small amounts of a black viscous oil have been obtained. This oil is not pumped readily without warming up, but analysis shows that it contains an unexpectedly high percentage of light oils.

While there have been several widely separated wells, they have been located without particular regard to testing the main structural features or the most promising horizons. As a result,[2] the Canadian area has been actually tested in but few significant localities. Several important gas fields have been developed, notably those at Bow Island and Medicine Hat in southern Alberta. The first named field supplies the City of Calgary and intervening towns. Gas has also been found in recent wells drilled in the vicinity of the Sweet Grass Hills near the international boundary, and at Havre in Montana.[1] The oldest producing gas well in the area is that drilled by the Canadian Geological Survey at Pelican Rapids on the Athabasca River in 1897, and this has been blowing open ever since. Several other more recent wells in the same locality have yielded smaller supplies. A recent test of the Battle River anticline (1914) five miles north of Viking, Alberta, has also developed a considerable flow of gas.

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[1] McConnell, R. G., Can. Geol. Surv., Vol. 5D, pp. 1–57.

[2] Malcolm, Wyatt, Can. Geol. Surv., Memoir 29E, and Huntley, L. G., Bull. A. I. M. E., June, 1915.

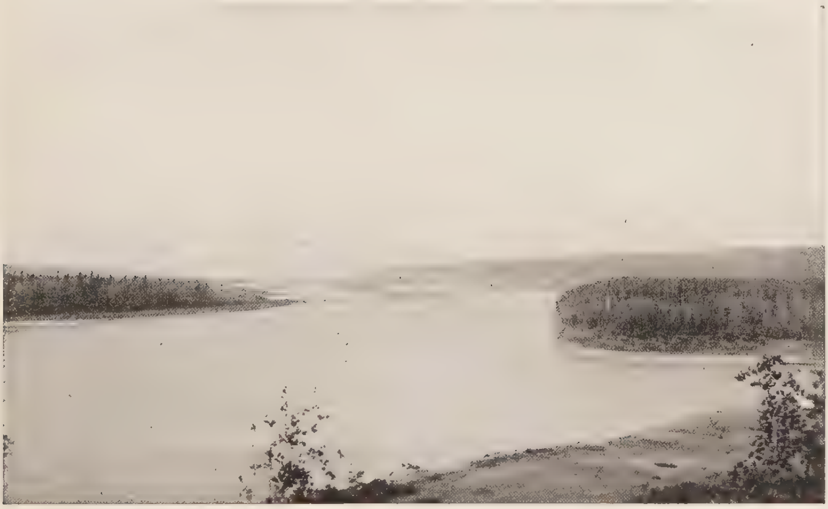

FIG. 94. Showing the ledge of Devonian limestone with the overlying "tar sands" (Cretaceous) along the lower Athabasca River.

All of the localities mentioned except Medicine Hat produce gas from the Dakota sand horizon (Fig. 95), which is identical with the "tar sands" of the Athabasca River. Many other wells have been drilled which have encountered gas in the shales and sandy lenses of the beds overlying the Dakota, but thus far these flows have been very short-lived. Among others, the wells at Athabasca Landing, Victoria, Vegreville, Tofield, Wetaskawin, Calgary, Suffield, and Minot (South Dakota), have encountered pockets of this shale gas. The promising Glendive anticline, extending southeast from Glendive, Montana, is now being tested, although the public land is withdrawn.

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[1] Stebinger, E. Possibilities of Oil and Gas in North-central Montana. U. S. Geol. Sur. Bull. 641 C.

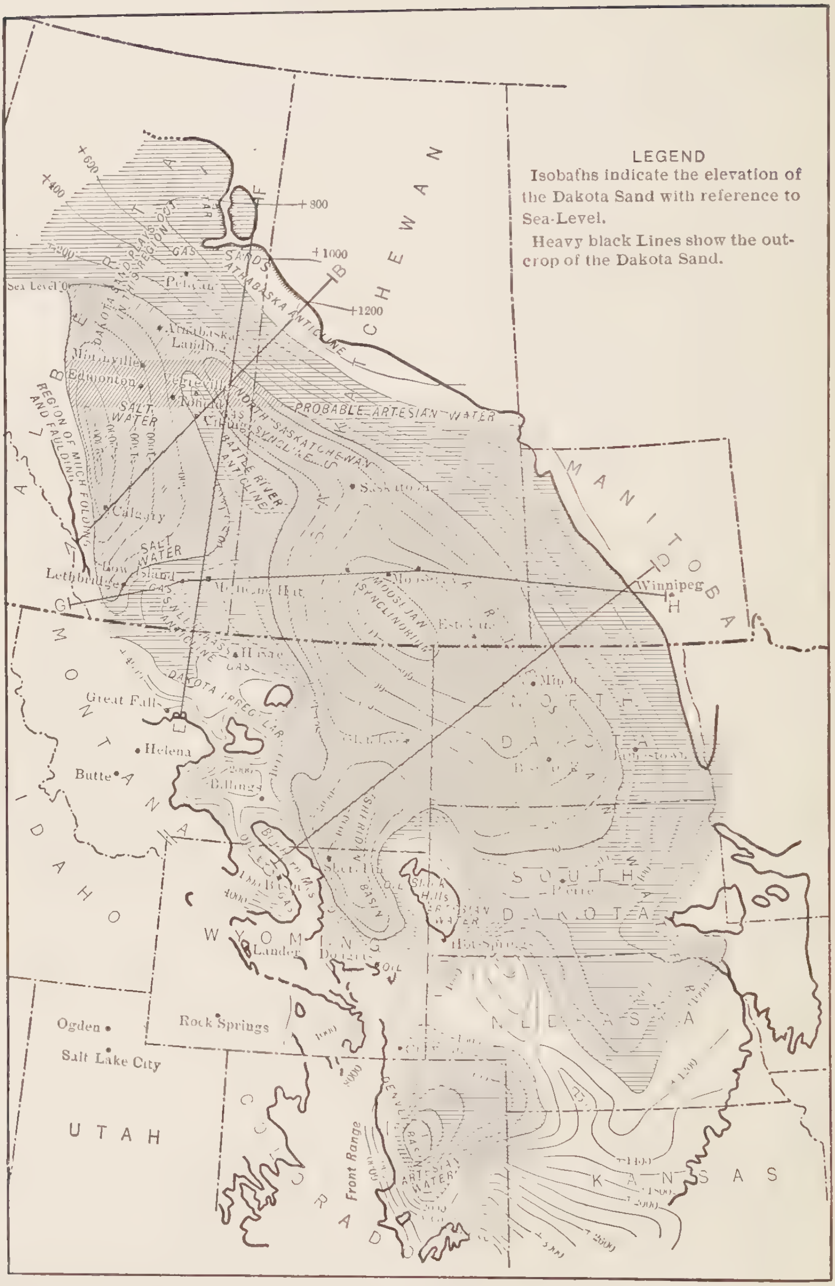

Fig. 95. Sketch map showing generalized structure of the Dakota sand in the United States and Canada, with relation to the oil, gas, and water reservoirs in that sand.

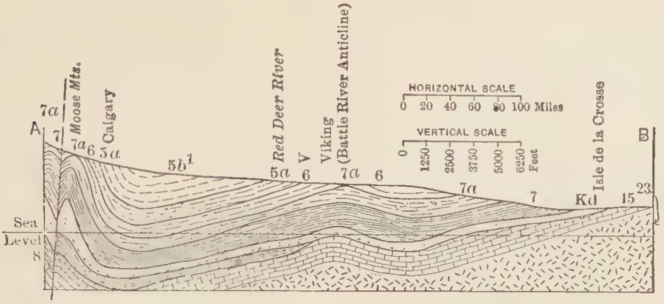

FIG. 96. Section along *A–B* of Fig. 95.

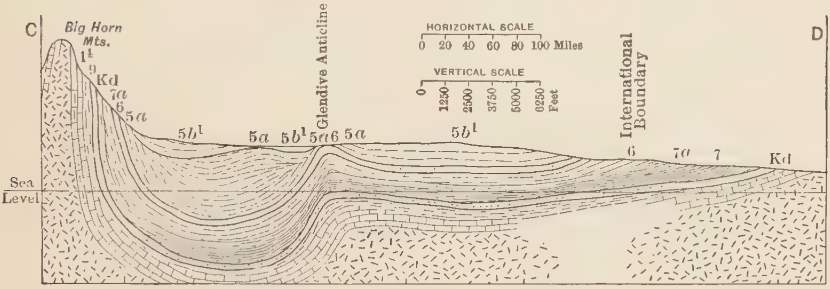

FIG. 97. Section along *C–D* of Fig. 95.

Legend — (applies to sections, Figs. 96, 97, 98, 99)

Lower Tertiary.	$5b^1$, Laramie — Paskapoo Series.	Fresh-water sands, clays and shales.
Upper Cretaceous.	*5a*. Laramie—Edmonton Series (coal bearing).	Sand and shales.
Upper Cretaceous.	5, Bearpaw (Pierre-Foxhill).	Gray-brown shales, sand shells.
Upper Cretaceous. *7a*	Belly River and Lower Dark shales.	Sand and shale in upper portion, black shale below.
	Niobrara (cardium).	Sand lenses and dark shales.
	Benton.	Black and gray shales.
Upper Cretaceous.	Kd, Dakota sand.	Soft, porous sand (250 to 950 ft.), conglomeratic at base.
Lower Cretaceous.	8, Kootenay shales (coal-bearing).	
Devonian.	15, Devonian.	Limestones, shale, and salt or gypsum.
Cambrian.	18, Cambrian.	Reddish sand and shales.
Archean.	23, Laurentian.	Granite.

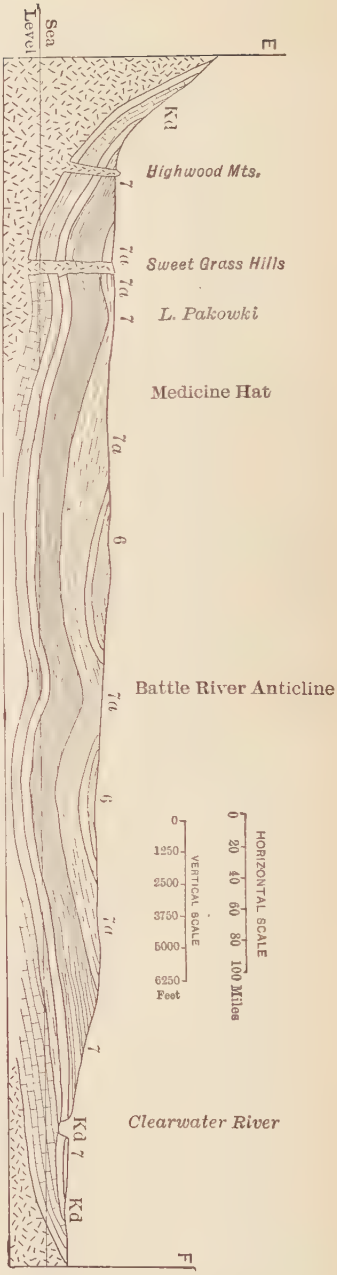

Fig. 98. Section along *E–F* of Fig. 95.

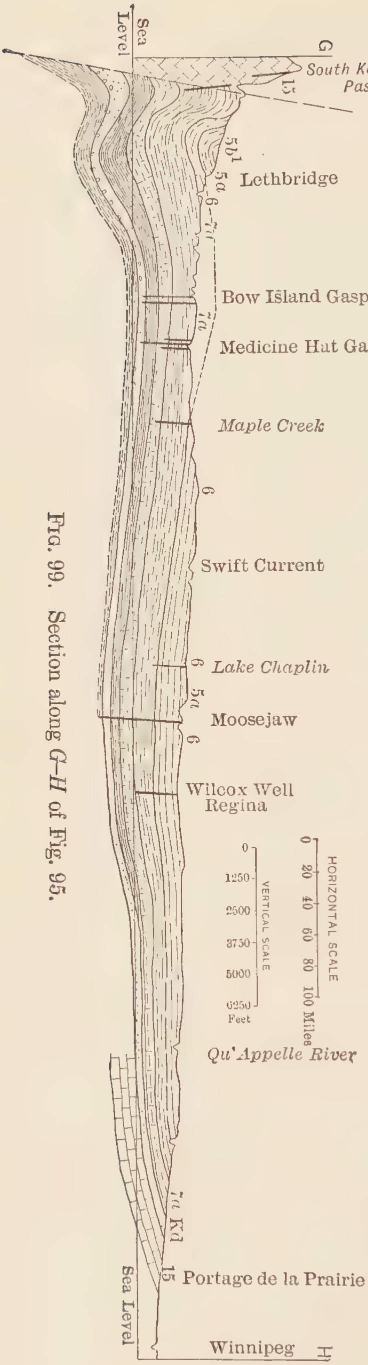

Fig. 99. Section along *G–H* of Fig. 95.

The formations underlying this entire field are shale and sands of Upper Cretaceous age. In the main structural basins (Calgary and Moosejaw syncline), these are overlain by Laramie (Tertiary) beds of varying thickness which at Calgary are approximately 2000 feet in thickness (Fig. 100). The Cretaceous sediments, which are the most promising for the oil prospector, vary in thickness from a few hundred feet along the eastern and northern edges of the basin to as much as 3500 feet in the western part of the area. This, combined with the overlying Laramie (Tertiary), makes a total thickness of at least 5500 feet in the center of the Calgary Basin, and approximately 3000 feet in the center of the Moosejaw syncline (Figs. 96, 97, 98, 99). The upper Laramie (Tertiary) beds are largely of fresh water origin, while conditions throughout the deposition of the Cretaceous varied at intervals from marine deposits to brackish water, and consist largely of light gray to black shales interbedded with inconstant sand lenses.[1] The proportion of sand to shale increases to the west and the shales contain frequent intercalations of harder sandstone "shells" near the mountains. With the exception of these hard sand "shells," the formations are soft and

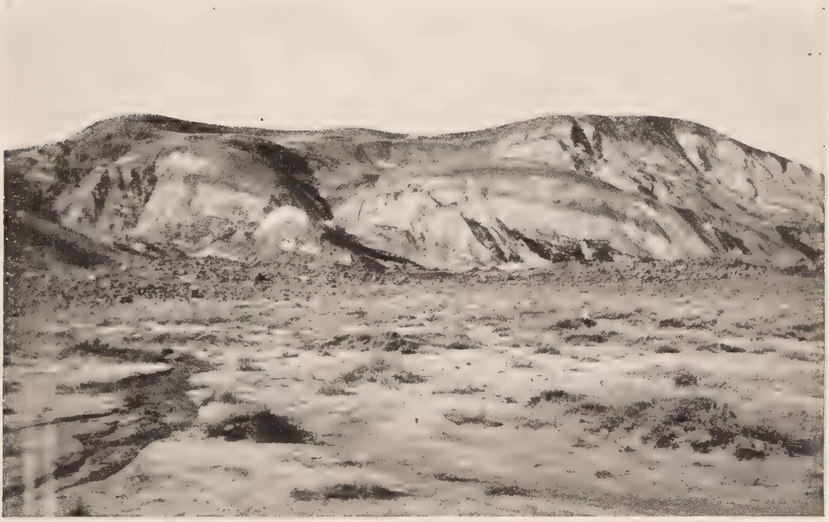

Fig. 100. Showing strong folding in the formation at the northern end of the Calgary Basin in Alberta.

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[1] Dowling, D. B., Bull. A. I. M. E., June, 1915.

somewhat unconsolidated, so that trouble is encountered in drilling on account of caving.

The restricted sand lenses in the Colorado shales (Benton, Niobrara and "lower dark" shales) are promising horizons for the oil prospector, while the widely distributed and uniformly porous Dakota sand unless infeasibly deep should always be tested in all wells before drilling is stopped. These marine and brackish water carbonaceous shales indicate a probable source of petroleum, which should be looked for in near-by sands. The general "sheet" character of the Dakota sand, and its artesian water content in the eastern part of this field, should be taken into consideration[1] in prospecting for oil in this bed. The following may be said to comprise the best prospects for future development:

(1) Back from the outcrop of the "tar sands," especially where there is a dome.

(2) The district northwest of Edmonton and Athabasca Landing where the Dakota sand begins to tail out and so becomes lenticular and independent of the Athabasca River leakage. Favorable structure is known to exist in this district.

(3) The Battle River anticline. This is very favorable for gas in the Dakota sand, and less so for oil and gas in the sands of the Colorado shales. The pressure is lower than at Bow Island, but the fields will be quite extensive.

(4) Further prospecting on the Sweet Grass (Montana) anticline for both gas and oil, although more favorable for the former.

(5) The Glendive (or Cedar Creek) anticline in Montana for both gas and oil now withdrawn.

(6) The Porcupine dome[2] in Montana.

(7) A small dome about 20 miles southeast of Oelrichs, South Dakota, in the Pine Ridge Indian Reservation. This has not been withdrawn.

(8) Southeast of (7) and crossing the state line into Nebraska is a second larger dome[3] which exposes the Niobrara in the valley of the White River. The Dakota lies at a minimum depth of 1200 feet from the surface at the crest of this dome.

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[1] Huntley, L. G., Bull. A. I. M. E., June, 1915.

[2] Bowen, C. F., "Possibilities of Oil in the Porcupine Dome," Mont. U. S. G. S. Bull. 621F.

[3] Darton, U. S. Geol. Surv., Folio 85 and Prof. Paper 32, and Water Supply Paper 227.

(9) A low broad anticline crosses the Platte River in Nebraska, near the junction of the north and south branches, the crest of which Darton shows to be in the vicinity of Stockville, Frontier County. This is a relatively low broad structure, which brings the Dakota sand from 700 to 1400 feet of the surface. The Dakota on the flanks of this anticline is water-saturated, but there is a possibility of gas production along part of its crest.

It must be said that of the three structures last named (6, 7 and 8) that (9) is the least favorable. Both gas and oil seepages are known on the flanks of the Black Hills uplift, and while water conditions in the Dakota may be considered detrimental to the chances of finding oil in this formation on these domes, yet from a structural standpoint they are comparable to the Salt Creek dome in Wyoming, and should be tested. The Graneros shale member above the Dakota is known to be petroliferous in this region.

(10) Certain areas back from the outcrop of the Dakota, where local structure or other conditions may have served to retain oil.

The public lands of other areas[1] of more or less promise have been withdrawn from entry by the U. S. Land Office. These are mainly in the states of Montana and Wyoming.

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[1] Ball, Max W., Petroleum Withdrawals and Restorations, U. S. Geol. Survey Bull. 623.

CRETACEOUS FORMATION IN THE NORTHWESTERN PLAINS.

Groups.	Western Montana.	Southern Alberta.			Central Montana.	Manitoba.	South Dakota.
			West Forks of Milk River.	East near Pakowki Coulee.			
Montana group	Bearpaw shales (*Marine*)	Foxhills Pierre	Bearpaw shales (*Marine*)	Bearpaw shales (*Marine*)	Bearpaw shales (*Marine*)	Odanah shales (*Marine*)	Foxhills
	Two Medicine formation (*Fresh and brackish*)	Belly River formation	"Pale" and "Yellow" beds sandstones and clays (*Fresh and brackish*).	"Pale" and "Yellow" beds sandstones and clays (*Fresh and brackish*)	Judith River formation (*Mainly fresh water*)		Pierre
			Shale at Forks	Shale in coulee (*Marine*)	Claggett shales (*Marine*)	Millwood shales (*Marine*)	
	Virgelle sandstone		"Castellated" rocks	"Castellated" rocks of Milk River	Eagle sandstone		(*Marine*)
Colorado group	Benton shales (*Marine*)	Lower dark shales (*Marine*)			Benton shales (*Marine*)	Niobrara shales (*Marine*) Benton shales (*Marine*)	Niobrara shales (*Marine*) Benton shales (*Marine*)
Dakota group		Exposures of sandstones in the Sweet Grass Hills, and also reached by drilling in Alberta.			Exposures in Sweet Grass Hills		

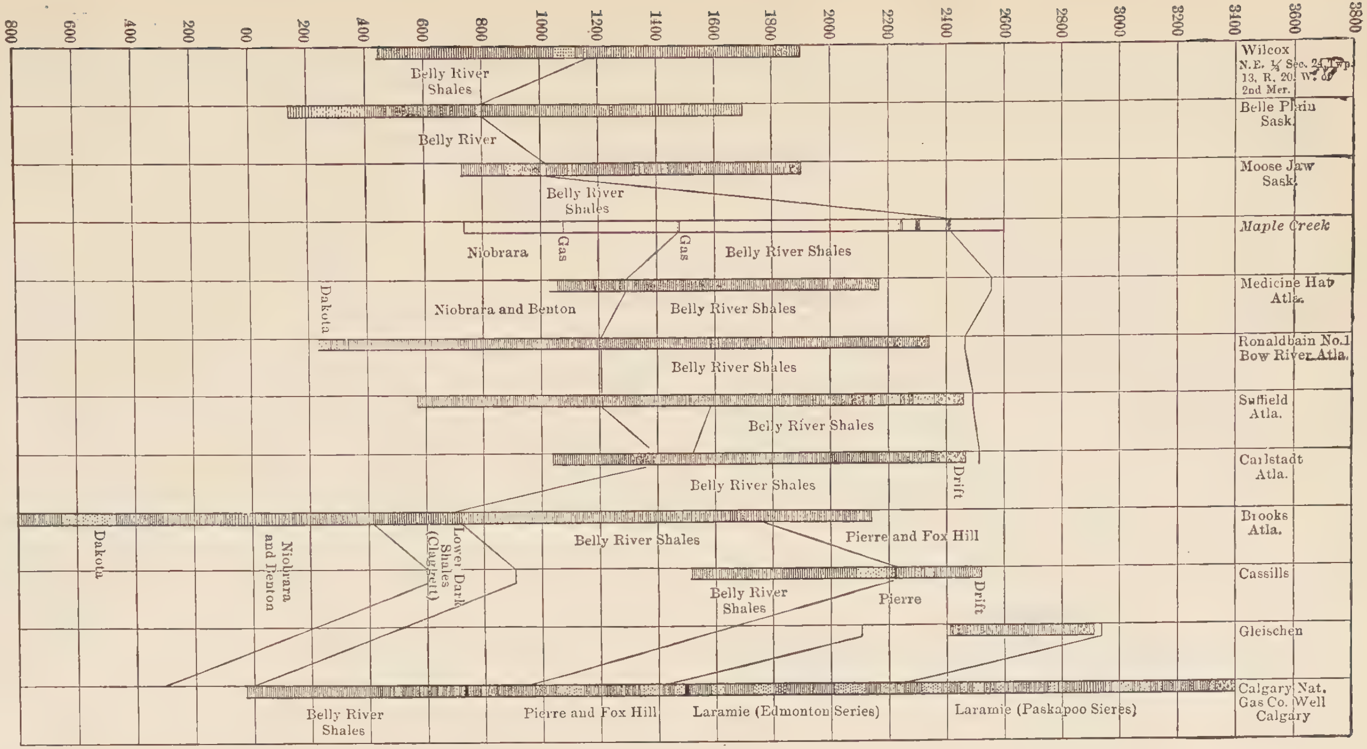


Fig. 101. Tentative correlations of the formations in Alberta upon the evidence of well logs.

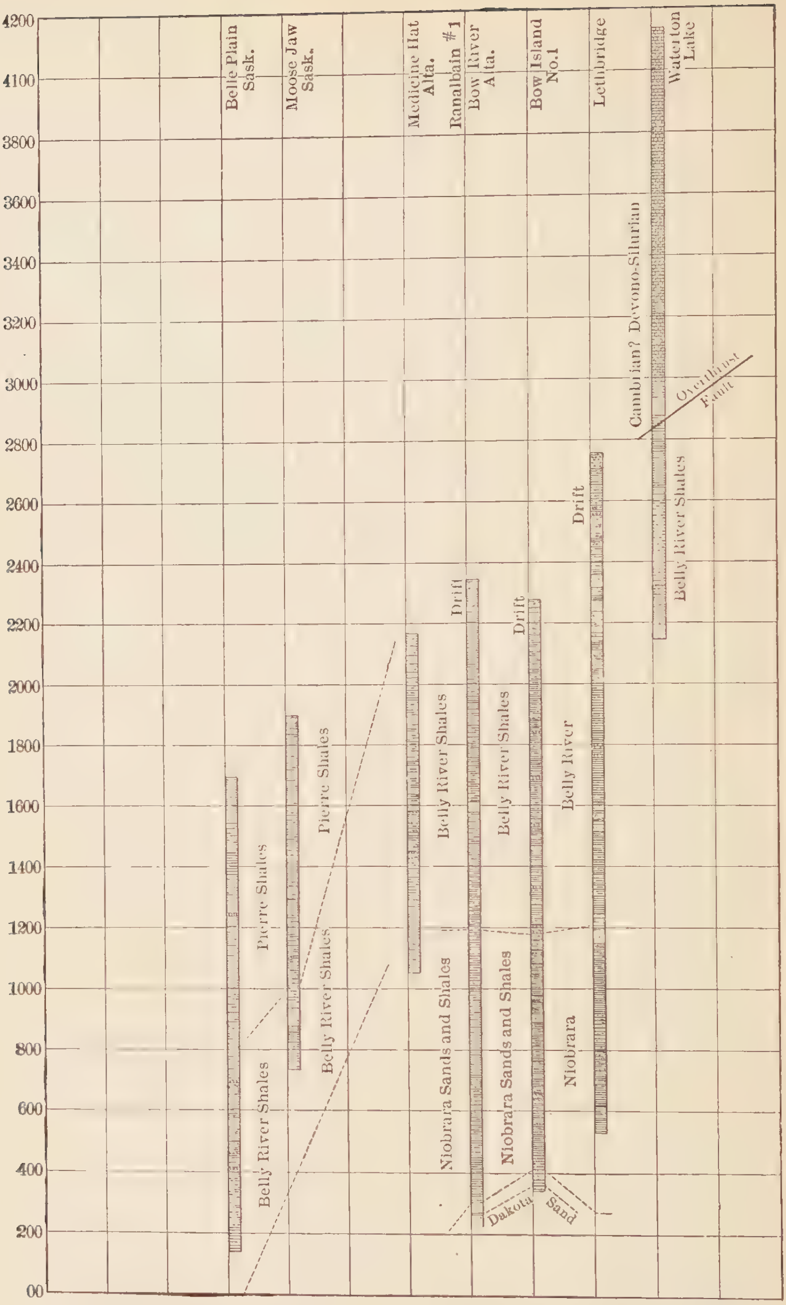


FIG. 102. Tentative correlations of the formations in southern Alberta upon the evidence of well logs.

Canadian Foot-hills

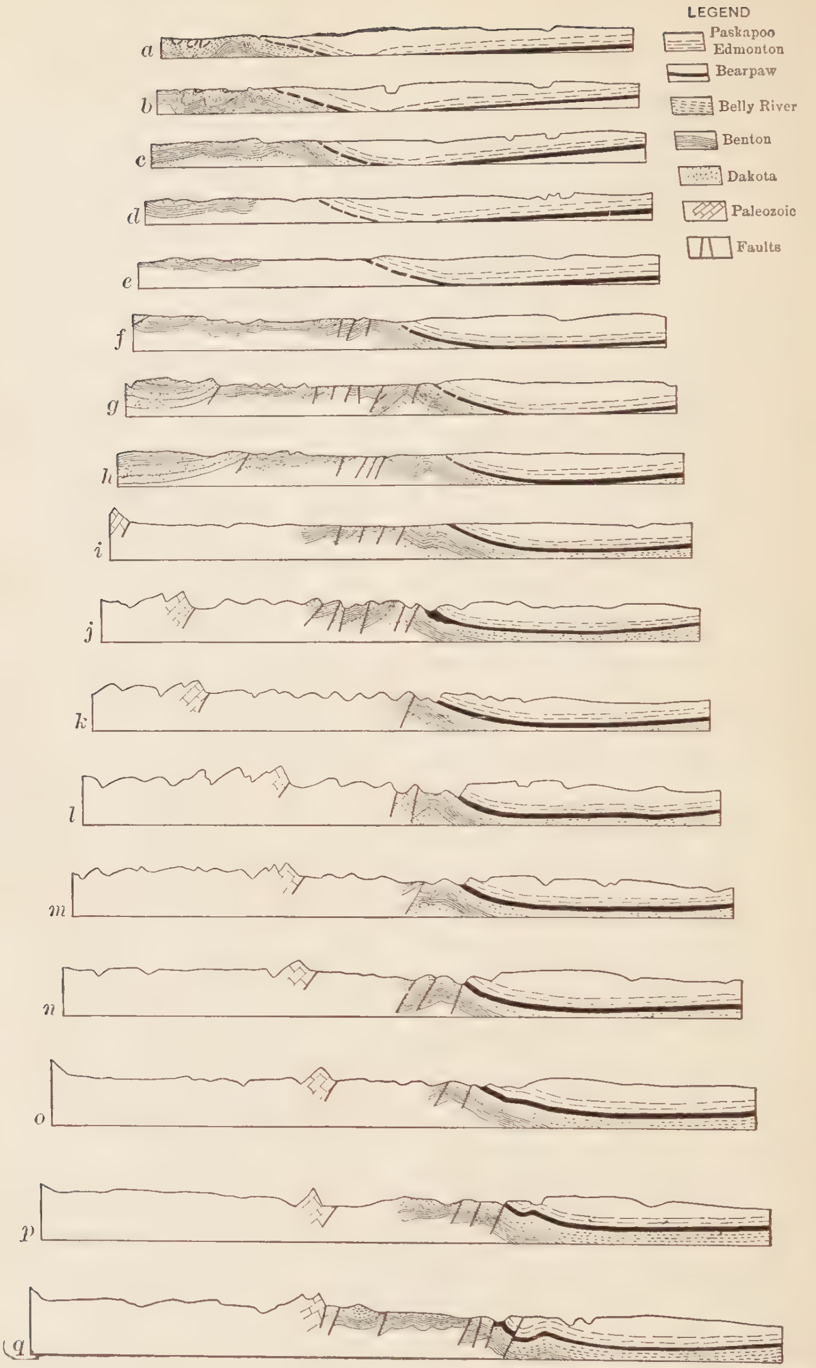
This field comprises the narrow belt between the Northwestern Plains and the Rocky Mountains, where the formations have been sharply folded at the time of the great mountain uplift at the close of the Cretaceous epoch. The formations are frequently faulted within the greater part of this belt, although this disturbance is less northwest of Calgary.

A small amount of oil was once produced from several wells in the South Kootenay Pass district, in the extreme southwestern corner of Alberta, but never in commercial quantities. A number of seepages occur in this district, exuding from Cretaceous formations and from rocks as old as the Cambrian. About thirty wells have been drilled since 1904. A great overthrust fault exists in this district, which probably accounts for some of these anomalous occurrences of oil.

During 1913–14 there was a great deal of drilling carried on in what is known as the Calgary field, though the activity really centered in the Sheep River district southwest of Calgary. In all about fifty wells have been drilled, one or two to a depth of about 4000 feet. Gas was encountered in a number of these wells, so rich in heavy hydrocarbons as to be very suitable for the condensation of gasoline, if it were found in sufficient quantities. Several wells also encountered small quantities of very light oil, but there had been no commercial production up to the end of the summer of 1915, when operations were very much curtailed. Several wells were also drilled in the districts north and west of Calgary, but without important results.

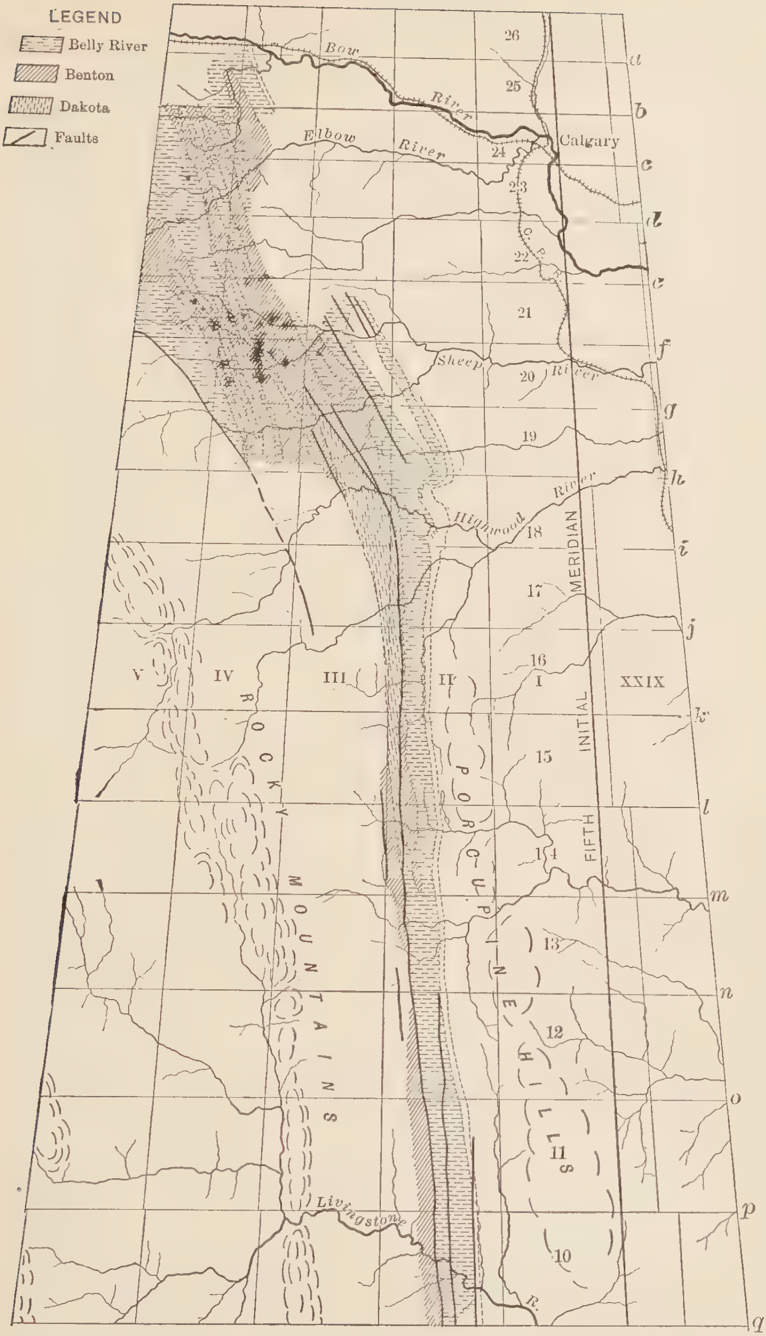
The geological section is the same as that of the Cretaceous formations of the plains to the east, except that the strata are considerably thicker and contain more sand, and compacting caused by the pressure of folding has solidified the shales to some extent. This thickening of the formations has increased the drilling depth to such a point that it will probably be unprofitable to attempt to reach the most promising horizons (Colorado shales and the Dakota sand) except where sharp anticlines have brought them nearer to the surface. These sharp folds, in connection with frequent faults, increase the possibility of leakage.

Unlike some other more favorable foothill belts, such as the Appalachian, there is no corresponding, gradual transition from these steep faulted folds to more gentle ones further away from the mountains. The descent to the bottom of the Calgary basin is so relatively abrupt that any promising horizons that might exist are at such a depth



Dowling, Bull. A. I. M. E., June, 1915.

FIG. 103. Structure sections of foot-hills of southern Alberta.



Dowling, Bull. A. I. M. E., June, 1915.

FIG. 104. Perspective diagram of the foot-hills of southern Alberta.

as to make drilling unprofitable, even though salt water were not encountered.

This belt becomes wider and the folds more promising to the northwest of Calgary. With improved transportation facilities, production may be developed in the northern part of this field. The southern part of this area, where most of the drilling has been done up to 1915, does not appear promising.

These Cretaceous formations are underlain by the Kootenay shales (Lower Cretaceous), and limestones and shales of Carboniferous and Devono-Silurian age.[1] They are of no practical importance to the oil operator or prospector, because the overlying Cretaceous formations are so thick as to necessitate infeasibly deep drilling except near the mountains where they are too steeply folded (Figs. 103 and 104).

Nova Scotia, New Brunswick and Quebec Field

This field[2] includes several irregularly shaped areas in Nova Scotia and New Brunswick, in which are deposits of albertite and oil shales, the Stony Creek gas field 10 miles south of Moncton, New Brunswick, and the Gaspé Peninsula of Quebec, where about 54 wells were drilled without success between 1900 and 1902.

The only oil production from this field is a small one derived from mining oil shales occurring at several horizons in the lowest Carboniferous and the Devonian formations. However, the Stony Creek gas field, which is being developed by the Maritime Oil Fields Company, shows a little oil in some of its wells. The gas wells in this field show initial pressures of from 20 to 600 pounds, and individual wells are estimated to have produced as high as 6,400,000 cubic feet of gas per day. They are, however, short-lived, and soon decline to very low pressure and little production. The wells drilled near oil seepages, occurring along several sharp anticlines and faults on the Gaspé peninsula, never produced oil in commercial quantities, although several of them were pumped for a time. From the 54 wells drilled, averaging 2000 feet deep or more, the total amount of oil produced was probably less than 1000 barrels. The field is now abandoned. The formations are of Devonian age, and show a promising alternation of carbonaceous shales, sandstones and limestones, which have nevertheless proved disappointing. The dips in this area are from 10 to 80 degrees, and three well-marked anticlines occur. From 8 to 10 oil seepages are known, one of them in a drusy igneous rock constituting a dike.

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[1] Dowling, D. B., "Correlation and Geological Structure of the Alberta Oil Fields," Bull. A. I. M. E., June, 1915.

[2] Summary Report, Canadian Geol. Surv., 1876–7.

The oil shales and deposits of albertite have been mined in Nova Scotia in Pictou, Hants and Antigomish Counties; and in Albert and Westmoreland Counties in New Brunswick. Oil shales also exist on the Gaspé peninsula in Quebec. Besides these Carboniferous and Devonian oil shales, the Utica shale (Ordovician) is petroliferous at its outcrops along the St. Lawrence valley and elsewhere, and was worked in the early sixties before the discovery of oil in wells at Petrolia in Ontario.

There have been a great many wells drilled at various places in these provinces, but without success. The Ordovician has produced a little gas between Montreal and Quebec (Three Rivers), but otherwise such efforts have been disappointing. The formations are badly folded and metamorphosed at many places, and cut by faults and igneous intrusions. However, with the broadening market for petroleum and its increased price in the future, the oil shales of Canada will probably be extensively developed.

The small quantities of petroleum produced at Gaspé and Stony Creek were paraffin oils of light gravity.

Erie Field

The Erie field comprises the Ontario peninsula and that part of the oil and gas fields of New York, Pennsylvania and central Ohio which produce from the Lower Devonian and Silurian formations. Except for an area running south through central Ohio, this field centers around Lake Erie.

Practically all of Canada's oil production in the past has come from this field, and until the opening of the Bow Island and Medicine Hat fields in Alberta in recent years, the same was true of her natural gas production. This field includes the small oil and gas production from northern Chatauqua, northern Cattaraugus, Niagara, Orleans, Genesee, Wyoming, Monroe, Wayne, Livingston, Ontario, Oswego and Onondaga Counties in New York, and Erie County in Pennsylvania. In

Guide Book No. 1, Can. Dept. of Mines, Part II, pp. 359–361.

Ells, R. W., Can. Geol. Surv., Ann. Rept., 1902–3, The Oil Fields of Gaspé, pp. 340–362.

Ells, R. W., The Albert Shale Deposits of Albert and Westmoreland Counties, New Brunswick, pp. 363–379. Op. cit.

Ells, R. W., Rept. 55, Mines Branch, Geol. Surv. Can.

Ohio this field comprises the gas fields of Cuyahoga, Lake and Ashtabula Counties (including the recent development in the Clinton Sand near Cleveland[1] and Ashtabula), all of the great central Ohio gas belt producing from the Clinton sand in Ashland, Richland, Knox, Licking and Hocking Counties, the Wooster oil and gas production in Wayne County, and the Bremen and New Straitsville oil pools in Perry County, all producing from the Clinton sand.

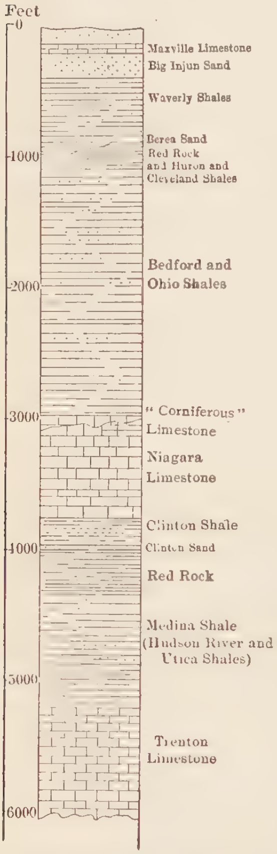

FIG. 105. Typical section in the central Ohio field.

Fig. 105 shows a generalized section for this field. The Clinton formation of Ohio is believed to correspond to the Medina sands of New York and Ontario, and is the most important oil and gas horizon in this field. There is, however, some shallow shale gas produced along the Ohio-Pennsylvania-New York lake front from the Bedford and Ohio shales and the lower Devonian shales of New York.

In Ontario,[2] the principal oil production (in Lambton County) comes from the "Corniferous" limestone (Dundee formation) above the Niagara, while the oil and gas in the Tilbury-Romney field (Kent County) and surrounding territory comes from the Guelph shales. Practically all the rest of the oil and gas production in Ontario comes from the Clinton-Medina horizon in a narrow belt extending west from Niagara Falls for a distance of 90 miles. Recent wells drilled to the Trenton limestone at Oil Springs in Lambton County obtained some gas. Two wells drilled at Milton in Halton County obtained a little light paraffin oil in the Ordovician shales, at a depth of about 1400 feet.

In New York[3] small quantities of gas are found in all the formations from the shales of the Lower Devonian (Oriskany) to the Potsdam sandstone (Cambrian), including the Medina and Oswego sandstones, the Pulaski and Utica shales, and the Trenton limestone. Drilling started about 1885, but so far has failed to develop any important pools. The initial wells were frequently of very high pressure, but proved small and of short life.

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[1] Bownocker, J. A., The Cleveland Gas Field. Science n. ser., Vol. 43, p. 397.

[2] Petroleum and Natural Gas in Canada, Vol. II. Canada Mines Branch, No. 291.

[3] Orton, Edw., Bull. N. Y. State Mus., Vol. 6, No. 30.

The general structure of the Ohio portion of this field is that of a gentle homocline dipping a little south of east. Accumulations of oil and gas (central Ohio gas field) are found along the up-dip edge of the Clinton sand where it tails out into the surrounding shales. Somewhat disturbed structure is found at Bremen,[1] but in general, textural conditions have a more important effect upon the accumulations of oil and gas in this field than do the small irregularities in the general structure. The Clinton sand in Ohio contains little if any water and so has prevented the scattered oil content from being concentrated in as large quantities as would otherwise have been the case.

In New York and Ontario practically the same conditions prevail, the dip being very gentle and uniform, and the accumulations small and erratic. The local porosity and thickness of the sands seem to be the governing factors in the accumulation of both gas and oil, rather than the changing gradient. The gas belt along the Erie lake front in Ontario is limited in width because the Clinton and Medina sands tail out to the northward. The Petrolia and Oil Springs oil pools in Lambton County, Ontario, are, however, located on well-marked folds, as is the Bothwell pool in Kent County.

The gas from the Clinton and Medina horizons is nearly odorless, dry, methane gas, containing from 2.5 to 12.4 per cent of nitrogen, and has an average heating value of slightly less than 1000 B.T.U. per cubic foot. In this it averages slightly less than the gas from the Appalachian fields.

In Ontario the oil field in Lambton County is slowly declining, with slight prospects of new territory being opened up. There is, however, a chance of deeper gas in the underlying Trenton, and several wells drilled at Oil Springs have encountered a considerable flow from that formation. In Ohio deeper drilling to the Clinton east of the central gas fields will continue to bring in small pools. These pools will, however, probably continue to be "spotty" and not particularly prolific, so that a considerable increase in the price of oil will be necessary to warrant drilling wells to the necessary depths, in extending production eastward. In New York the formations have been widely tested, and only relatively small low-pressure gas wells are being obtained at present.

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[1] Bownocker, J. A., The Bremen Oil Field, Geol. Surv. of Ohio, 4th Ser., Bull. 12.

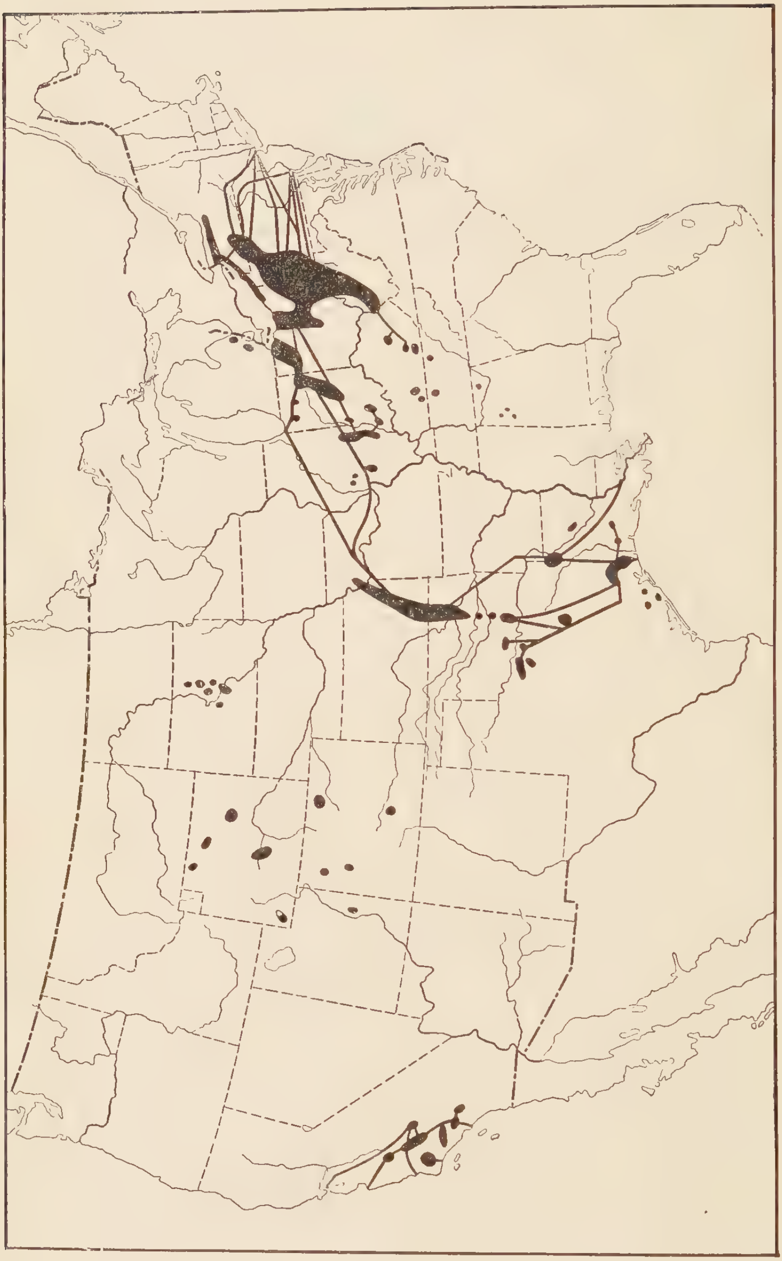

FIG. 106. The principal oil and gas fields of the United States with the principal oil pipe lines. After Schuchert's Historical Geology.

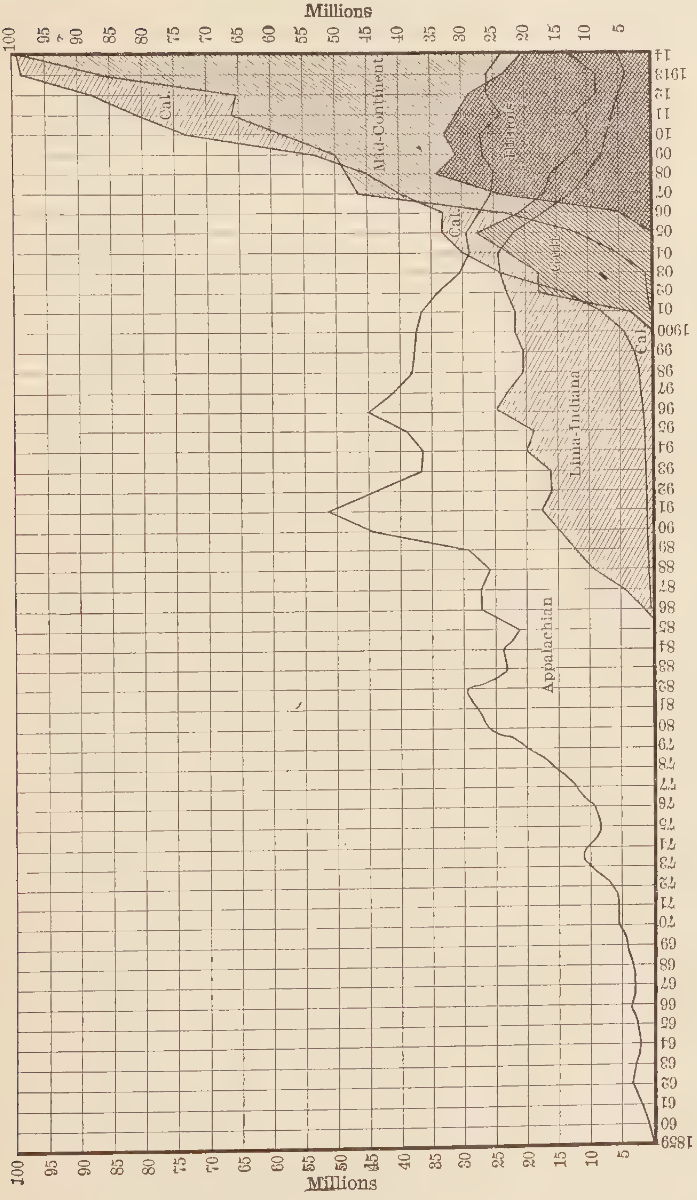

Fig. 107. Showing the production of the main oil fields of the United States.

The Appalachian Fields

The oil industry of the United States started with the famous well drilled in 1859 by Col. Drake, near Titusville in Pennsylvania. Early explorers and settlers reported oil springs and the use of the product of such exudations by the Indians for medicinal purposes; but no serious attempts were made toward its recovery on a large scale prior to 1859. From that time, prospecting has developed prolific pools from time to time in many of the western counties of Pennsylvania (Fig. 108) and West Virginia, in southeastern Ohio and eastern Kentucky. Later drilling has developed oil and gas in Tennessee and gas in northern Alabama

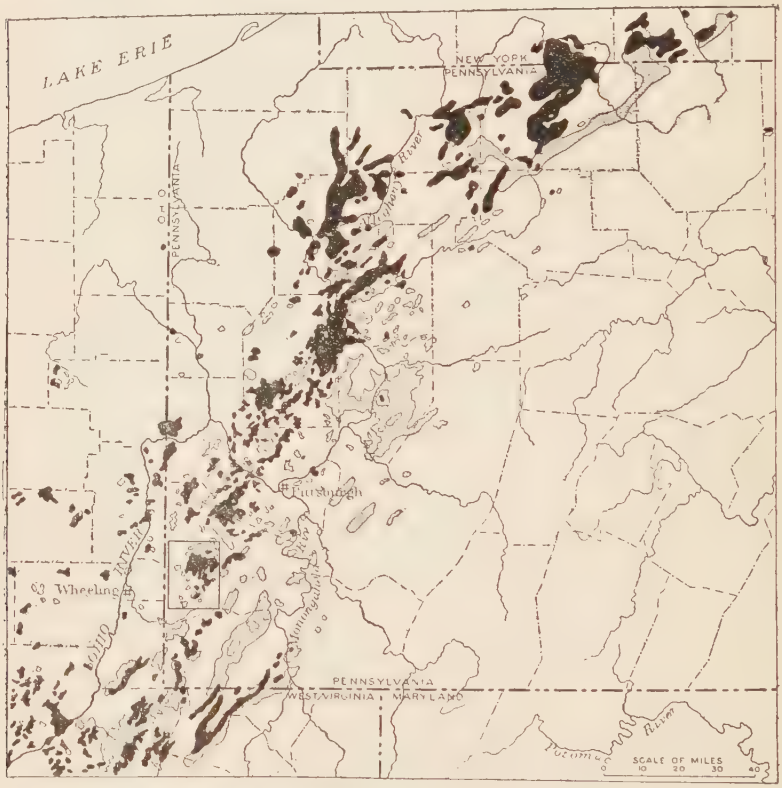

FIG. 108. Sketch map of underground oil and gas pools in Devonian and Mississippian strata of Pennsylvania and adjoining states. Black areas, oil pools; dotted areas, gas. After M. J. Munn, U. S. Geol. Surv.

(Fig. 92). For the purposes of this discussion, only those fields are included which lie on the western flanks of the Appalachian Mountains and produce oil or gas from the Carboniferous or Upper Devonian formations.

From the early beginning near Titusville, the production from these fields reached its maximum in 1891, at the time of the opening up of the McDonald and neighboring pools in Allegheny and Washington Counties, Pennsylvania. In that year these fields produced approximately 51,000,000 barrels (Fig. 107). Since that time other large pools have been opened up in West Virginia and Ohio, but none large enough to prevent the gradual decline of production, which in 1914 amounted to only 24,000,000 barrels.

At the present time prospecting and development is more active in West Virginia than in other parts of the Appalachian fields, although in 1915 there were two small pools opened up in Pennsylvania, e.g., at Evans City in Butler County, Pa., and at Dorseyville in Allegheny County. The first of these was a "town-lot proposition," which ran the characteristic course of such developments, and will result in a profit for only two or three companies at most, out of the large number involved.

The geological section is a very favorable one of alternating sandstone and shale, with the latter in excess (Fig. 109). The sand horizons are much more persistent in extent and more characteristic than are those found in most fields. The dips are gentle, with the general direction both of the reservoirs and the folds, in the majority of horizons, parallel to the mountains. The farther away from the mountains the less this holds true.

The Gaines pool in Pennsylvania is reported to produce oil from formations inclined locally from 3 to 10 degrees, but such dips are more exceptional for the Appalachian fields. In Tennessee the formations are reported as compact, with fewer strata sufficiently porous to act as oil or gas reservoirs, than is the case in the north.

Drilling in the more active districts in West Virginia ranges from 2200 to 3000 feet in depth. The more favorable areas and structures have been tested, so that operations are now being carried on in the less accessible districts and are relatively expensive. The operations from now on will consist largely of testing areas nearer the mountains for low-pressure gas, and of drilling deeper in old pools for both gas and oil. For reasons which have been discussed, it is believed that large supplies of deep gas will be developed, and also that relatively low-pressure gas will be developed on a number of the steeper folds east from the present fields. This steep eastern belt is unfavorable for oil. An indication of the cost of operating at a profit under present conditions can be gained from the fact that $2.60 per barrel does not greatly stimulate drilling.

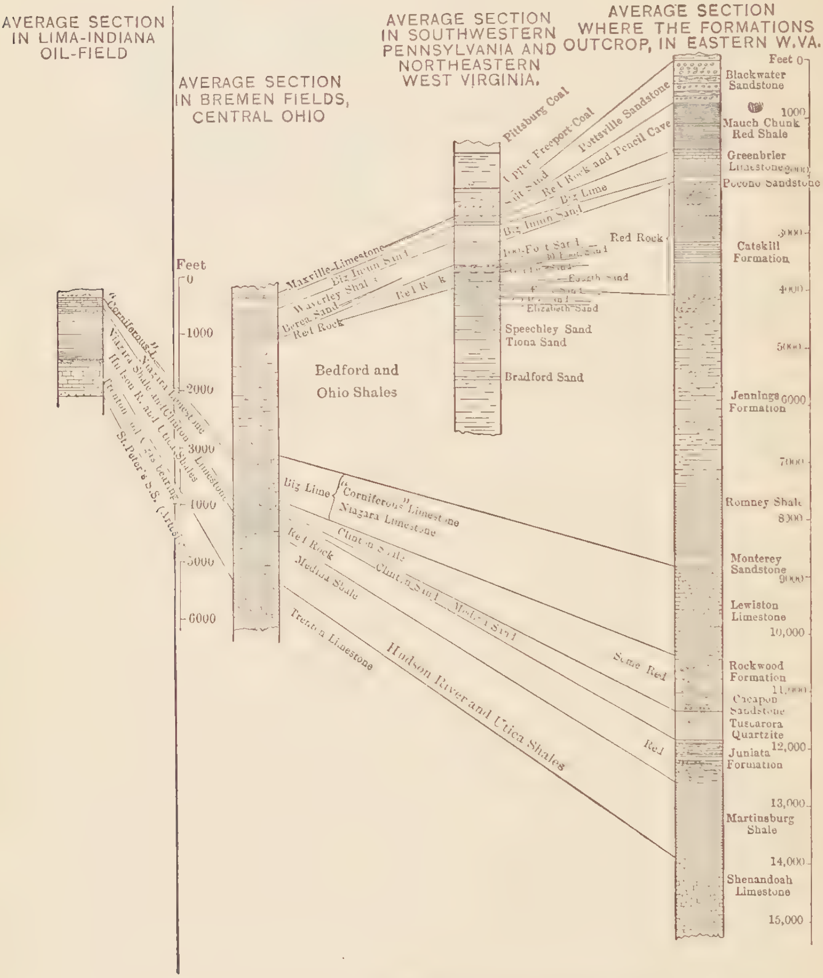

FIG. 109. Correlation of strata from West to East through the Lima-Indiana, central Ohio and Appalachian fields. After Clapp and others.

The oil from the Appalachian fields averages about 44° B., and is a paraffin oil without asphalt and commands the highest price for crude oil paid anywhere in North America. This is, however, only partly due to its quality, for it has the great advantage of being close to good markets for refinery products, and it benefits by ample pipe line and refinery facilities. (Fig. 106.)

As these fields are old, with few new features developing which are of interest to the industry as a whole, and as most of the modern operating practices are being developed elsewhere under new conditions, they will not be described in detail.[1]

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[1] Carrl, J. F., The Geology of the Oil Regions of Warren, Venango, Clarion and Butler Counties, Pennsylvania, Second Geol. Surv. of Pa., Vol. III.
Bownocker, J. A., The Occurrence and Exploitation of Petroleum and Natural Gas in Ohio, Geol. Surv. of Ohio, Fourth Series, Bull. 1.
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U. S. Geological Survey:

Geol. Folio 94 Brownsville-Connellsville. Campbell, M. R.
177 Burgettstown-Carnegie. Shaw, E. W.; Munn, M. J.
178 Foxburg-Clarion. Shaw, E. W.; Lines, E. F.; Munn, M. J.
180 Claysville, Pa. Munn, M. J.
102 Indiana, Pa. Richardson, G. B.
125 Rural Valley, Pa. Butts, Charles
176 Sewickley, Pa. Munn, M. J.
92 Gaines, Pa.-N. Y. Fuller, M. L.
172 Warren, Pa.-N. Y. Butts, C.
144 Amity, Pa. Clapp, F. G.
121 Waynesburg, Pa. Stone, R. W.
115 Kittanning, Pa. Butts, C.; Leverett, F.
82 Masontown-Uniontown. Campbell, M. R.
146 Rogersville, Pa. Clapp, F. G.
123 Elder's Ridge, Pa. Stone, R. W.
Bulletin 275 The Hyner Gas Pool, Clinton County, Pa. Fuller, M. L.
275 Oil and Gas Fields of eastern Greene County, Pa. Stone, R. W.
531 Geological structure of the Punxsutawney, Curwensville, Houtzdale, Barnesboro and Patton quadrangles, in Central Pennsylvania. Ashley, G. H.; and Campbell, M. R.
304 Oil and Gas Fields of Greene County, Pa. Stone, R. W. and Clapp. F. G.
300 Economic Geology of the Amity quadrangle in eastern Washington County, Pa. Clapp, F. G.

Mid-Continent

This field as here discussed corresponds fairly closely to the Western Interior Coal Basin. It consists roughly of the area of outcrop of the Pennsylvanian rocks of Iowa, Missouri, Nebraska, Kansas, Arkansas and Oklahoma north of the Ouachita-Arbuckle-Wichita Mountains. Since there is a small amount of production in this area in rocks older than the Pennsylvanian, there may be some extension to the east. The extension to the westward is more surely indicated and has already been begun. This is not only because these beds dip under the Permian to the west and can be reached by drilling through them, but also because the lowermost Permian is proving productive. As deeper drilling is encouraged by higher prices, a wide zone of this Permian area will be included.

There is a great variety in the grade of oil produced — from that near Humboldt of 28° B. with 5 per cent naphtha, to that of Cushing of 41° B., with 25.8 per cent naphtha. While most of it is asphaltic oil, clear oil is obtained in pools at Muskogee, Morris, Cleveland, Red Fork, Bigheart and Ponca, although asphaltic oil is obtained from other pools near most of these towns. That the price is, at the time of going to press, still uniform for all grades except Healdton

286 Economic Geology of the Beaver quadrangle, Pa. Woolsley, L. H.
285 The Nineveh and Gordon Oil Sands in western Greene County, Pa. Clapp, F. G.
279 Economic Geology of the Kittanning and Rural Valley quadrangles, Pa. Butts, Chas.
454 Coal, Oil and Gas in the Foxburg quadrangle. Shaw, E. W. and Munn, M. J.
456 Oil and Gas Fields of the Carnegie quadrangle, Pa. Munn, M. J.
541 Oil and Gas in the northern part of the Cadiz quadrangle, Ohio. Condit, D. D.
318 Geology of the Oil and Gas Fields of the Steubenville, Burgettstown and Claysville quadrangles, Ohio, West Virginia and Pennsylvania. Griswold, W. T. and Munn, M. J.
579 Reconnaisance of Oil and Gas Fields in Wayne and McCreary Counties, Ky. Munn, M. J.
621 h-Anticlines in the Clinton sand near Wooster, Wayne Co., Ohio. Bonine, C. A.
621 n-Structure of the Berea Oil Sand in the Summerfield quadrangle, Ohio. Condit, D. D.
621 o-Structure of the Berea Oil Sand in the Woodsfield quadrangle. Condit, D.D.

is the result of the fact that the oil of the over-producing Cushing pool was of high grade. Yet eventually different prices for different grades must surely result for so great is the contrast between Cushing

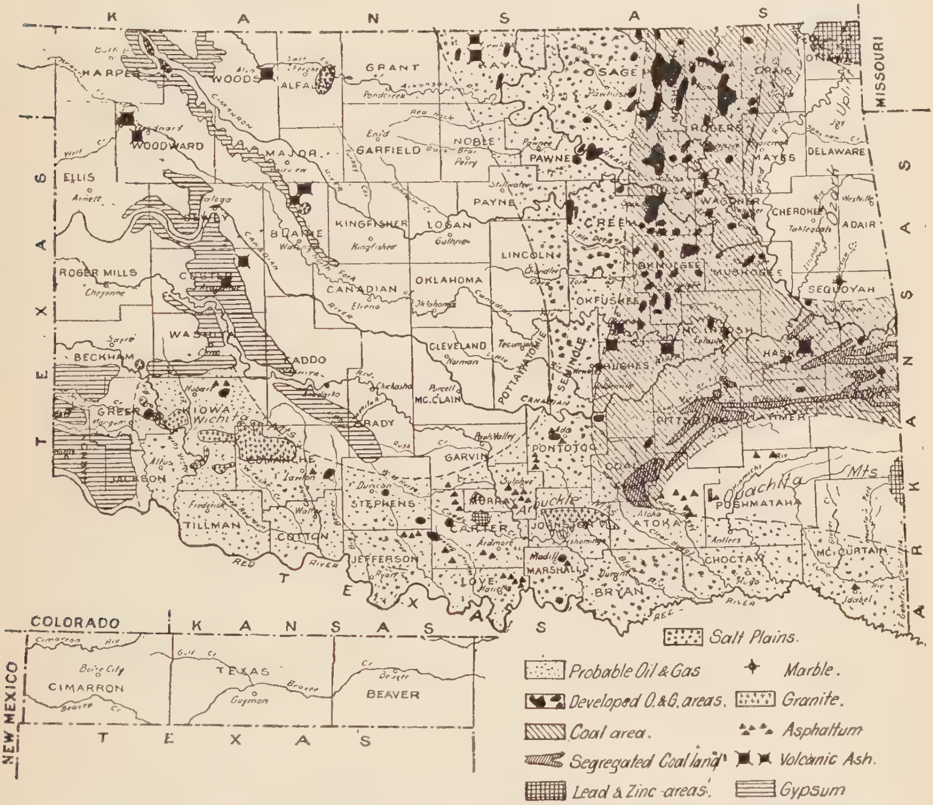

FIG. 110. Map of Oklahoma showing distribution of mineral resources. Oklahoma State Geol. Surv.

and other Oklahoma oil, as is shown in the accompanying table from Davies, Wing and Carroll.[1]

The productive sands are for the main part in the Middle and Upper Pennsylvanian. Throughout Kansas and northern Oklahoma it is the custom to discontinue drilling test wells at the great unconformity on top of the Boone chert (Mississippi lime) because the chert is very

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[1] Davies, Wing and Carroll, "Conditions in the Healdton Oil Field," Oklahoma. U. S. Bureau of Corporations, March 15, 1915.

Crude oil and product.	Gravity, deg. B.	Per cent yield.	Gallons.	Price per gallon.	Amount.
Average Oklahoma (laboratory):					
Naphtha	59.6	8.1	3.402	0.06621	0.22525
Kerosene	42.2	38.5	16.170	0.04796	0.77551
Lubricants	29.1	26.1	10.962	0.02500	0.27405
Fuel oil	.....	26.5	11.130	0.01875	0.20869
Total	.....	.....	....	....	1.48350
Cushing (laboratory):					
Naphtha	58.5	25.8	10.836	0.06621	0.71745
Kerosene	42.3	32.0	13.440	0.04796	0.64458
Lubricants	29.5	23.2	9.744	0.02500	0.24360
Fuel oil	.....	17.5	7.350	0.01875	0.13781
Total	.....	.....	....	....	1.74344
Average Oklahoma (refinery):					
Gasoline	.....	19.52	8.20	0.07081	0.58064
Kerosene	.....	18.13	7.61	0.04796	0.36498
Gas oil	.....	2.41	1.01	0.04500	0.04545
Fuel oil	.....	58.33	24.50	0.01875	0.45938
Total	.....	.....	....	....	1.45045
Glenn (refinery):					
Gasoline	.....	17.69	7.43	0.07081	0.52612
Kerosene	.....	17.28	7.26	0.04796	0.34819
Fuel oil	.....	60.64	25.47	0.01875	0.47756
Total	.....	.....	....	....	1.35187
Cushing (refinery):					
Gasoline	.....	30.90	12.98	0.07081	0.91911
Kerosene	.....	25.00	10.50	0.04796	0.50358
Gas oil	.....	15.00	6.30	0.04500	0.28350
Fuel oil	.....	27.00	11.34	0.01875	0.21263
Total	.....	.....	....	....	1.91882

difficult to drill and because there has been little success below it. A recent well in the Osage is reported by R. H. Wood to have yielded oil and gas below the Boone chert. This sand seems to be the Burgen sand (which is correlated with the St. Peters sandstone). It is not likely that many tests will be carried on to this formation at the present prices. In Rogers County, Oklahoma, to the south, there is another limestone bed, the Morrow and Pitkin, which is found above the Boone. This is not infrequently mistaken for the Boone because of its position and because the Pitkin is frequently cherty. Where it is so, much of it drills up into black, fine chips frequently called black sand, while the Boone more frequently gives larger white chips like the chert of the Joplin mines which is in this formation. The distinction is important because the Fayetteville formation which lies between the two formations carries a productive sand at Muskogee, Mounds and elsewhere.

Two very marked sedimentary overlaps from the south are evident. One is at the top of the Boone, and the other at the top of the Morrow and Pitkin. South of the Arkansas River, therefore, the Boone chert is frequently not reached before the well is abandoned on account of the depth.

The general attitude of the field is best described in two parts. The first part is that northwest of the Stigler-McAlester line. This is a geohomocline dipping in general about 11 degrees north of west, and having a dip of 25–50 feet to the mile, except toward the Ouachita and Arbuckle Mountains, where it is much steeper, and where the dip swings around to the north. Southwest of this line is an east and west geosyncline extending half way across the state of Arkansas. This geosyncline is much affected by well-marked anticlines, for the most part running in the same general direction. The geohomocline to the north, however, has folds of a very gentle sort, irregular and with little uniformity of direction, except for some well-marked east-west folds at the southern end.

The larger amount of folding to the southeast made the coals there quite hard (low volatile content). In accordance with White's law and his map, then, we expect gas, and but little if any oil east of a line roughly drawn from Sallisaw to Wilburton. And the oil nearest this line would be lighter. It will be possible to locate this line more exactly when more coals have been analyzed and mapped.

The Mid-Continent field has sands which are more porous than those of the Appalachian field as a whole, and as a result its wells in general start larger and show a more rapid decline. In two instances, Cushing[1] and Glenn, the reservoir has been so large and thick as not only to make these pools world-famous, but to have had a most depressing effect even upon the price of Eastern oil (1914–15). Neither of these pools has shown the persistence of the valley pools in California, although they are very much better in this respect than those of northern Louisiana.

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[1] Johnson and Huntley, The Influence of the Cushing Pool upon the Oil Industry. Proc. of Eng. Soc. West. Penn., Vol. 31, pp. 40–487.

MARKETED OIL PRODUCTION OF GLENN AND CUSHING POOLS

Year.	Glenn (barrels).	Cushing (barrels).
1906	1,000,000 (est.)	....
1907	19,926,995	....
1908	20,494,313	....
1909	18,946,740	....
1910	19,236,914	....
1911	13,880,118	....
1912	10,945,518	559,050
1913	9,469,870	8,181,660
1914	8,677,589	21,994,985
1915	....	73,884,749 [1]

[1] Inclusive of unmarketed oil and the near-by Fox pool.

The sand-bodies are in general so lenticular and the folds so gentle that the control of accumulation by structure is relatively less than by the shape of the reservoir. This is proved by the fact that the edges of the oil pools are more often caused by the tailing or "tightening" of the sand or by the oil giving way to gas or water. Haphazard wildcatting has been less futile than in most other fields for the reason that the dips are so gentle and the number of horizons so numerous that there is an area roughly 200 by 100 miles in extent with scattered pools. Within this area there are still many regions where the tests are far apart. Yet the percentage of successes in this haphazard drilling can be greatly increased by studies of attitude and more skilful "feeling out."

The prospects for future development are very bright. The map (Fig. 110) gives a large area in which new pools may be expected. Owing to the occasional occurrence of very thick sand-bodies, development will be checkered by an oscillating price produced by these "market-breaking" finds.

The best general discussions of the field are those of Hutchinson,[1] Snider,[2] Shannon and Trout.[3] To these should be added O'Hern [4] on the general stratigraphy, Buttram [5] on the Cushing pool, and Smith [6] on the Glenn. We may shortly expect from the U. S. Geological Survey reports upon the Pawhuska, Nowata, Vinita, Claremore, and Hominy quadrangles, which will be of great importance.

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[1] Hutchinson, L. L., Okla. Geol. Surv. Bull. 2.

[2] Snider, L. C., Petroleum and Natural Gas in Oklahoma, Harlow-Radcliff Co., Oklahoma City, Okla.

[3] Shannon, C. W. and Trout, L. E., Petroleum and Natural Gas in Oklahoma, Okla. Geol. Surv. Bull. 19, Pt. 1.

[4] O'Hern, D. W., Stratigraphy of the Older Pennsylvanian Rocks of Northeastern Oklahoma, Univ. Okla. Research Bull. 4.

[5] Buttram, Frank, Okla. Geol. Surv. Bull. 18.

[6] Smith, Carl D., U. S. G. S. Bull. 541, 34–48.

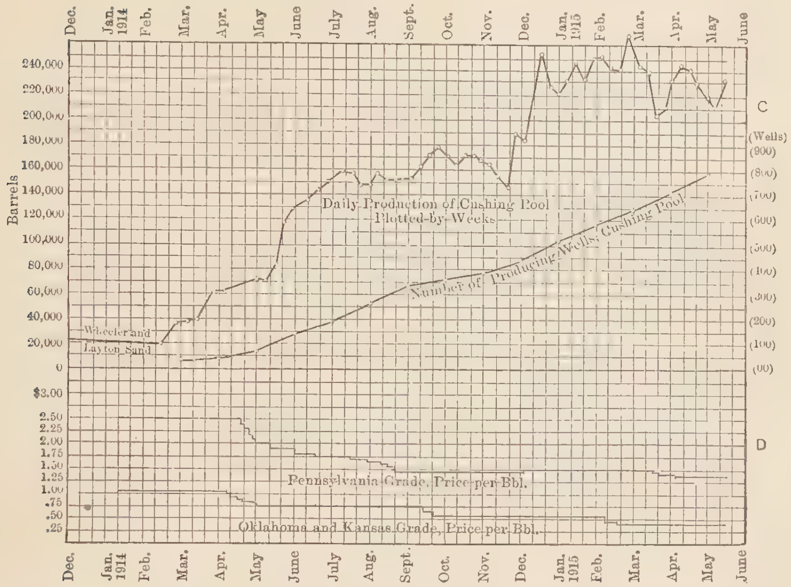

FIG. 111. Relation of the production of the Cushing Pool to the price of oil.

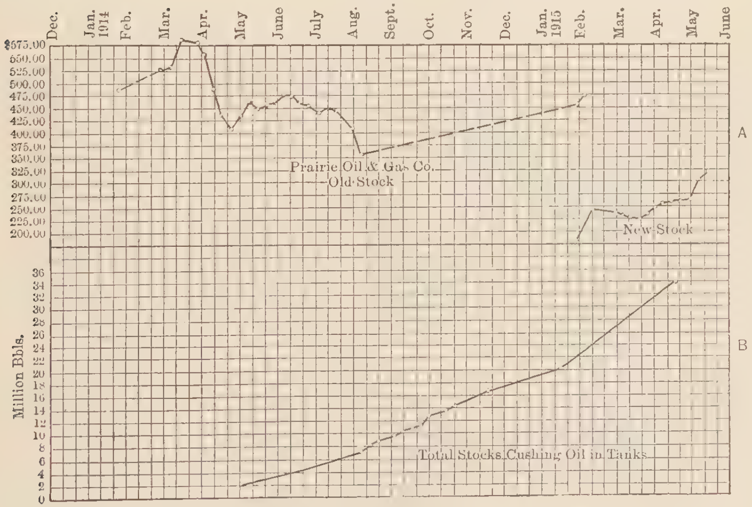

FIG. 112. Relation of the Cushing stocks to Prairie Oil and Gas Co. shares. Compare with Fig. 111.

The following references give structural maps of various parts of the field, or are otherwise noteworthy.

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U. S. G. S. Folios: Tahlequah, Coalgate, Atoka, Tishomingo, Independence.
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Fath, A. E. An Anticlinal Fold near Billings, Noble Co., Okla.
For a bibliography of the field see the Oklahoma Geological Survey Bull. 25.

MARKETED OIL PRODUCTION IN KANSAS AND OKLAHOMA

Year.	Kansas.		Oklahoma.		Kansas and Oklahoma.	
	Quantity (bbls.).	Price.	Quantity (bbls.).	Price.	Quantity (bbls.).	Price.
1889	500	....	....	....	500	....
1890	1,200	....	....	....	1,200	....
1891	1,400	....	30	....	1,430	....
1892	5,000	....	80	....	5,080	....
1893	18,000	....	10	....	18,010	....
1894	40,000	....	130	....	40,130	....
1895	44,430	....	37	....	44,467	....
1896	113,571	....	170	....	113,741	....
1897	81,098	....	625	....	81,723	....
1898	71,980	....	....	....	....	....
1899	69,700	....	....	....	....	....
1900	74,714	....	6,472	....	81,186	....
1901	179,151	....	10,000	....	189,151	....
1902	331,749	....	37,100	....	368,849	....
1903	932,214	....	138,911	....	1,071,125	....
1904	4,250,774	....	1,366,748	....	5,617,527	$0.970
1905	....	....	....	....	12,013,495	0.545
1906	....	....	....	....	21,718,648	0.443
1907	2,409,521	....	43,524,128	....	45,933,649	0.402
1908	1,801,781	....	45,798,765	....	47,600,546	0.387
1909	1,263,764	....	47,859,218	....	49,122,982	0.364
1910	1,128,668	....	52,028,718	....	53,157,386	0.383
1911	1,278,819	....	56,069,637	....	57,348,456	0.472
1912	1,592,796	....	51,427,071	....	53,019,867	0.674
1913	2,375,029	....	63,579,384	....	65,954,413	0.937
1914	3,103,585	$0.784	73,631,724	$0.778	76,735,309	0.779
1915	4,009,329	....	80,000,000	....	84,009,329	....

The total production of Oklahoma oil was much larger than the figures for marketed oil, since so great a quantity of Cushing oil was stored by the producers. The Fuel Oil Journal[1] estimates the total Oklahoma production in 1914 at 97,631,724 and in 1915 at 122,828,834.

South Mid-Continent

The axis formed by the Ouachita-Arbuckle-Wichita Mountains narrows the connection between the oil and gas fields in the Upper Pennsylvanian rocks which lie south of the axis, and the Mid-Continent field proper, lying north of the axis. This area is roughly that of the Texan coal field (exclusive of lignite), but includes a broad fringing zone on the west and crosses the Red River northward into Oklahoma to the mountains.

PRODUCTION OF PETROLEUM IN A PART OF THE SOUTH MID-CONTINENT FIELD, 1904–14

Year.	Petrolia.	Moran.	Electra and Burkburnett.	Total.
1904	65,455	....	....	65,455
1905	75,592	....	....	75,592
1906	111,072	....	....	111,072
1907	83,260	....	....	83,260
1908	85,963	....	....	85,963
1909	113,485	....	....	113,485
1910	126,531	....	....	126,531
1911	168,965	....	899,579	1,068,544
1912	197,421	....	4,227,104	4,424,525
1913	344,868	....	8,131,624	8,476,492
1914	550,585	68,191	8,277,968	8,896,744

Complete separate statistics of the total production of the Wheeler and the very productive Healdton pool are unfortunately not available, but the production[1] of Healdton, Okla., pool in 1915 was 6,909,293 barrels.

The attitude of the strata in this field, except for a few folds which are more marked to the north, is a homocline of unusually low westerly dips. Since the dips are so low, and the producing horizons lie in the uppermost Pennsylvanian, or the basal Permian beds, they are easily reached in a larger area through the Permian overburden. Faulting has brought up one block of Cambrian and Ordovician rocks, the Criner Hills, with some asphalt deposits. Nearly in line with this we have the Wheeler dome, with the same general axis. The Wheeler field is productive from the basal sandstone of the Permian.

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[1] Fuel Oil Journal, Feb., 1916.

Further out from the mountains in a southeasterly direction is the Duncan anticline, productive of gas from an 850-foot sand in the Permian, the Loco anticline, with a southwesterly axis and productive of gas from a 700-foot sand in the Permian, and a larger anticline, made up of many subsidiary domes at the important Healdton[1] pool.

Further out from the mountains lie the Petrolia dome and the more irregular and less well-developed folds mapped by Munn and Wegemann.

The area of the south Mid-Continent field[2] is very large, in comparison to that which has been prospected, and many new pools will doubtless be opened. To the north the beds were apparently subjected to more folding, and partly for this reason have received and will continue to receive more attention for some years to come than the flatter area southward. With improved deeper drilling methods and a higher price the area will be extended far westward.

The greatest pools have been at Electra, Texas, and at Healdton, Oklahoma. The Petrolia pool was the oldest and the Strawn pool to the south has been the last to be opened. Strawn has several sands, one as shallow as 800 feet. There is also a pool at Moran, Texas. The oil at Healdton is relatively heavy (31.57 degrees B.). It has 6.0 per cent naphtha and 0.70 per cent of sulphur.

The relative value of the products per barrel of Mid-Continent crude oil as given by Commissioner Davies[3] is:

Healdton	$1.329
Oklahoma (except Healdton and Cushing)	1.483
Cushing	1.743

In this calculation lubricants are given a price of $0.02½ a gallon, and fuel oil $0.01875. But since all of the lubricant fraction is not sold as such, but a great deal as fuel oil, the following values are given showing actual commercial runs, with the lubricant sold as fuel:

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[1] Wegemann, C. H., U. S. G. S. Bull. 621b.

[2] Udden, J. A. and Phillips, D. McN., Geology of Oil and Gas Fields of Wichita and Clay Counties, Texas. Bull. Univ. Tex. No. 246, pp. 103–4.

Gordon, C. H., Geology and Underground Waters of the Wichita Region, Texas. U. S. G. S. Water Supply Paper 317.

Taff, J. A., Geol. of the Arbuckle & Wichita Mts. U. S. G. S. Prof. Paper 31.

Munn, M. J., The Grandfield District, Oklahoma. U. S. G. S. Bull. 547.

Wegemann, C. H., Anticlinal Structure in Cotton and Jefferson Counties, and Northern Texas, Econ. Geol. X, pp. 422–434.

Shaw, Matson and Wegemann, Nat. Gas Resources of N. Texas, U. S. G. S. Bull. 629.

[3] Davies, Wing and Carroll, Conditions in the Healdton Oil Field, Oklahoma Bureau of Corporations, March 15, 1915.

RELATIVE VALUE OF OKLAHOMA AND NORTH TEXAS OIL

Grade.	Value of product.	Relative value with Healdton @ $0.75.
Healdton[1]	$1.204	$0.65
Electra	1.801	0.972
Cushing	1.919	1.036
Average Oklahoma	1.450	0.786

[1] Allowing $0.05 for sulphur treatment in Healdton oil.

While Healdton oil gets a much lower price, the other oils in this field rank well with Mid-Continent oils, and are now receiving nearly the same price. They are quoted in the following grades: Electra, Henrietta and Strawn.

While the Healdton and Petrolia pools are associated with well-marked anticlines, the Electra pool deserves especial attention because the beds are so very flat. Even to the south of the pool where a dip is noticeable, it is only 15 feet to the mile. Deformation has had little or no effect in this pool. Some of the producing sands lie so high stratigraphically that there is doubt as to whether or not they may be Permian.

Where the Permian overburden is quite thick there is much soft drilling. Notwithstanding this, in the main, cable tools are used.

An increase in production may be expected for several years, judging from the large area which has received so little testing and from the limited testing, thus far, of the deeper sands.

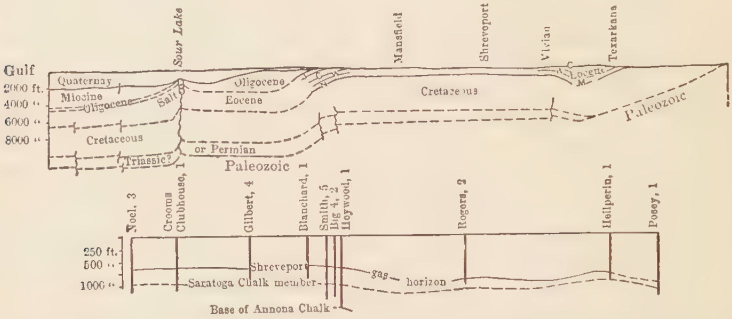
Veatch, U. S. G. S. Prof. Paper 46.
Gordon, C. H., U. S. G. S. W. S. Paper 276.
Harris, G. D., U. S. G. S. Bull. 429.
U. S. Geological Survey Bulletin 621.
Dumble, E. T., Bull. A. I. M. E., Aug., 1915, pp. 1623–38.
Phillips, W. B., Bull. Univ. Tex. No. 365, p. 23.
Vaughan, T. W., U. S. G. S. Bull. 142.
Deussen, A., U. S. G. S. W. S. Paper 335.
Munn, M. J., Tenn. Geol. Survey Bull. 2E.
Crider, A. F., U. S. G. S. Bull. 283, Geol. of Mississippi.

Gulf Cretaceous Field

The Gulf Cretaceous field at present may be said to comprise those areas lying inland from the Gulf Coast fields, under which the Cretaceous formations are found at depths that can be reached by the drill. This constitutes a belt extending from the Rio Grande at Eagle Pass in

Texas in a northeasterly direction through that state, up to and including the Sabine uplift in the vicinity of Caddo Lake in Louisiana (Figs. 92, 114–117), a part of southwestern Arkansas, and Oklahoma, south of the Arbuckle and Ouachita Mountains. These formations also extend into Mississippi, where several promising structures have been mapped.

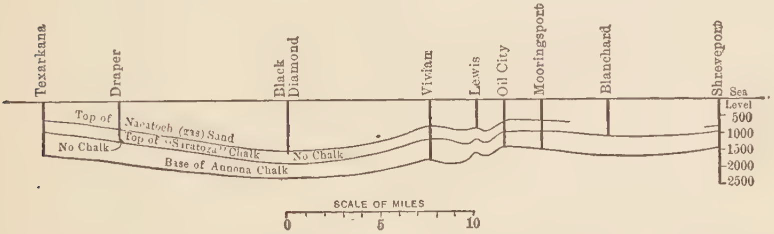
Up to the summer of 1915, oil pools have been developed within this area at Madill, Oklahoma, at Corsicana in Navarro County, Texas, at Powell in the same county, at Thrall in Williamson County, Texas, and in the Caddo-Critchton-Mansfield pools in Northwestern Louisiana. A well has also recently been drilled a few miles south of San Antonio in Bexar County, Texas.



After Harris.

Fig. 113. North-south sections of the Sabine uplift. Upper section extending from the Paleozoic outcrop in Arkansas, north of Texarkana, through the Caddo field and Sour Lake to the Gulf near Galveston. Lower section showing slight folds in Upper Cretaceous beds in the Caddo field, from Posey No. 1 well near Vivian to Noel No. 3 well near Mooringsport.

Of these the first named has had no production of consequence since 1910. The Gulf Cretaceous fields produced no oil of commercial importance prior to 1896, although Phillips mentions a small quantity as having come from the Dulling wells near San Antonio. In 1896 the Corsicana field was brought in, and remained the only producing field in north Texas until 1900. The Powell field, in the same county as Corsicana, was brought in during 1902; but it yields a heavier oil than the latter. The Caddo field, in Caddo Parish, Louisiana, was brought in during 1904, and what has proved a westward extension was developed in Marion County, Texas, during 1910. Up to the end of the year 1913, these fields had produced approximately 40,000,000 barrels of oil, more than a fourth of this being produced during 1913. In 1914 new pools were brought in at Critchton south of Shreveport, and at Thrall a few miles east of Taylor in Williamson County, Texas. The pool at Thrall was quickly defined, but that at Critchton continued to bring in good wells during 1915, and in July had developed a total production of approximately 33,227 barrels per day for Red River and De Soto parishes, as compared with 18,216 barrels per day for the older pools in Caddo Parish. The wells in these pools on the Sabine uplift have a notoriously rapid decline, and new wells must be drilled continually to prevent production from dropping rapidly.



After Harris.

FIG. 114. Generalized north-south section from Texarkana through the Caddo oil field.

In 1914 a small deposit of very light oil was found in the Trinity sand[1] at Mannsville, about 10 miles northwest of Madill, Oklahoma.

Asphalt has been found in the Trinity sand, the basal member of the Lower Cretaceous formations, in its exposures in Oklahoma south of the Arbuckle Mountains, and also in Burnett and Montague Counties in Texas. The limestones and shales of the Lower Cretaceous along the Devil's River in the Rio Grande basin are also reported by Udden to be saturated with petroleum in places, and to contain asphalt. No production has been developed in these Lower Cretaceous formations except in the Madill region in Oklahoma. These accumulations are supposed to be migratory oil from the underlying Paleozoic rocks.

In northeastern Texas and Louisiana the Woodbine formation furnishes the best production of all the wells on the Sabine uplift. Small quantities of oil are also reported by Dumble as having been produced about 1890 at Waco, from this formation. The Annona chalk (Annona chalk and Nacatoch gas sand) is productive in the Sabine fields, and its western equivalents, the upper Austin or basal Taylor, yield oil at Corsicana, Powell and Thrall, and in small shows at San Antonio.

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[1] Taff, J. A., Tishomingo quad., U. S. G. S. Geol. Folio 98.

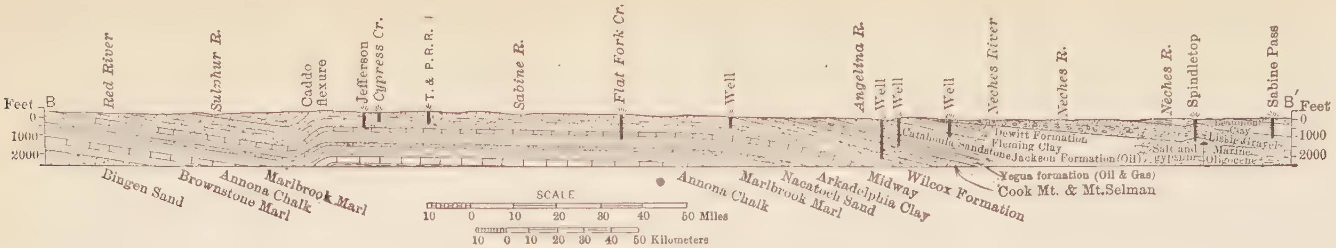
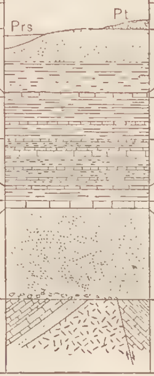


Fig. 115. Vertical section through the Sabine uplift.

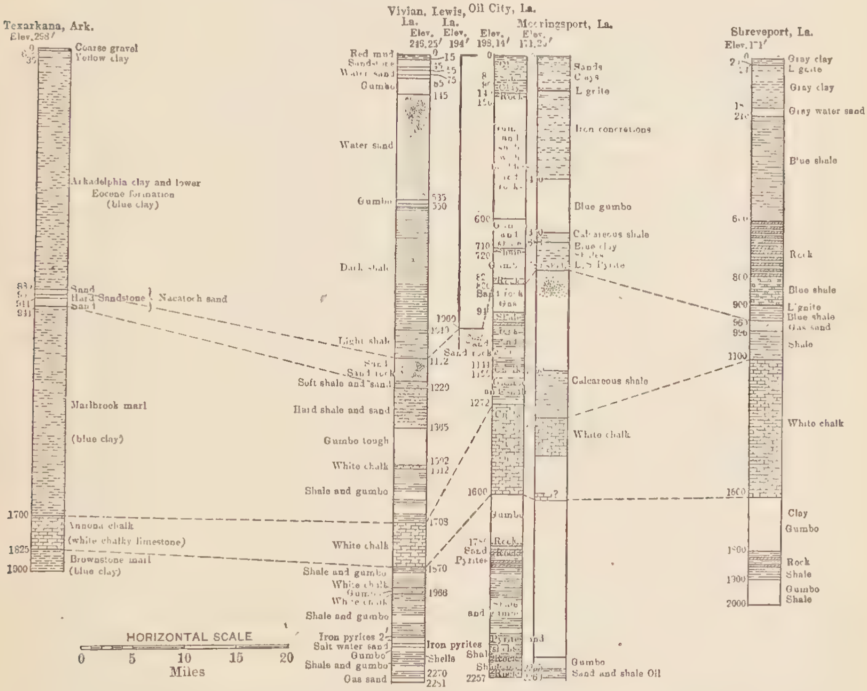
PERIOD		FORMATION NAME	SYMBOL	COLUMNAR SECTION	THICKNESS IN FEET	CHARACTER OF ROCKS
CRETACEOUS	GULF	River sand.	Prs	 Prs Pt		Fine river sand and silt.
		Terrace sand and gravel.	Pt		0–50	Gravel and sand.
		Silo sandstone.	Ks		200+	Brown friable sandstone, locally indurated by ferruginous cement, shale, and shaly sandstone.
		SLIGHT UNCONFORMITY				
	COMANCHE	Bennington limestone.	Kb		10–15	Blue limestone composed chiefly of shells.
		Bokchito formation.	Kbk		140	Red and blue shale with thin ferruginous limestone and lentils of friable sandstone.
		Caddo limestone.	Kc		150	Yellow and white limestone and marl.
		Kiamichi formation.	Kk		50	Blue friable shale; thin limestone composed chiefly of shells in upper portion.
		Goodland limestone.	Kgl		25	Massive white limestone.
		Trinity sand.	Kt		200–400	Fine yellow sand with conglomerate beds locally at the base.
		UNCONFORMITY Carboniferous, Devonian, Silurian, and Cambrian sediments and pre-Cambrian granite.				

Scale: 1 inch = 500 feet.

U. S. Geol. Surv. Folio 98.

Fig. 116. Generalized section for the southern part of the Tishomingo quadrangle.

Udden states that the oil in the Thrall pool is found in a porous serpentine derived by alteration from a flow of basalt. The oil is therefore believed to have migrated from the surrounding sedimentaries of either the Austin or Taylor formations. Asphalt is also found west of Uvalde[1] in the Anacacho limestone which may be the equivalent of the Annona chalk of eastern Texas.



After Harris.

FIG. 117. Details of sections from Texarkana to Shreveport showing data on which the generalized section (Fig. 113) is based.

There remain large unprospected tracts in these areas underlain by the Cretaceous formations. The U. S. Geological Survey[2] reports an anticline in Hinds County, Mississippi, as being worthy of test. All the formations of the Eocene and Upper Cretaceous between the Jackson formation and the Woodbine sand horizon of the Caddo field are within feasible drilling depth. Meanwhile, there still remain large areas for prospecting on the Sabine uplift, between Caddo and Corsicana in Texas. To the southwest the results at Thrall and San Antonio lead one to believe that larger pools will be found by the prospector. As the topography of much of this territory does not lend itself to detailed work in structural geology, the percentage of failures among the test wells may be high. This is particularly true since the strata vary in their character and in their porosity within short distances, since the sand-bodies are frequently lenticular, and the depositional gradients are therefore much more important in their effect on oil accumulation than are the local variations in the low dips which are prevalent in this region. While in general the massive limestone character of the Lower Cretaceous formations, as indicated by the sections in the Rio Grande Valley, is unfavorable for the development of oil pools, yet it may be that these formations are locally channeled or fractured or jointed. At such places oil accumulations may have been brought about through migration from overlying beds, as in the Vera Cruz-Tamaulipas field in Mexico. The fact that the outcrops show both oil and asphalt makes them appear more promising, and worthy of test where structural conditions are favorable. Vaughan describes a well-marked anticlinal fold a few miles northeast of Uvalde in Uvalde County, Texas. The Eagle Ford beds represent the surface formations, and a well drilled here might be expected to give information as to the petroliferous character of the underlying formations. In view of the basaltic and phonolite intrusions and frequent faults, in the vicinity, it must be admitted that the lack of seepages is an unfavorable feature in the search for oil in this region.

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[1] Vaughan, T. W., Uvalde quad., U. S. G. S. G. F. 64.

[2] Hopkins, O. B., Structure of the Vicksburg-Jackson area, Miss., U. S. Geol. Sur. Bull. 641 D.

Oil from the Caddo field varies in density in the different producing sands, from 10° to 60° B., but by far the greater part ranges from 37° to 42°. Corsicana oil is a high grade paraffin product, running about 52° B. The oil in the Madill pool is of about the same gravity, and contains no asphalt whatever, a condition which also holds true of the small quantity found at Mannsville to the north. Oil from the Powell field east of Corsicana is of a heavier grade, running about 33° B.

Michigan Field

This field includes almost the entire southern peninsula of the state of Michigan. The only region which has ever produced regularly is that of a few shallow wells at Port Huron, across the St. Clair River from Sarnia, Ontario. This is both stratigraphically and structurally a continuation of the oil field in Lambton County, Ontario. These wells at Port Huron have produced since about 1900, but now have a total production of less than 10 barrels per day. In spite of this low rate of yield, the character of the oil and of the producing formation is such that this rate has been maintained for ten or twelve years without appreciable decline, from wells between 500 and 600 feet deep.

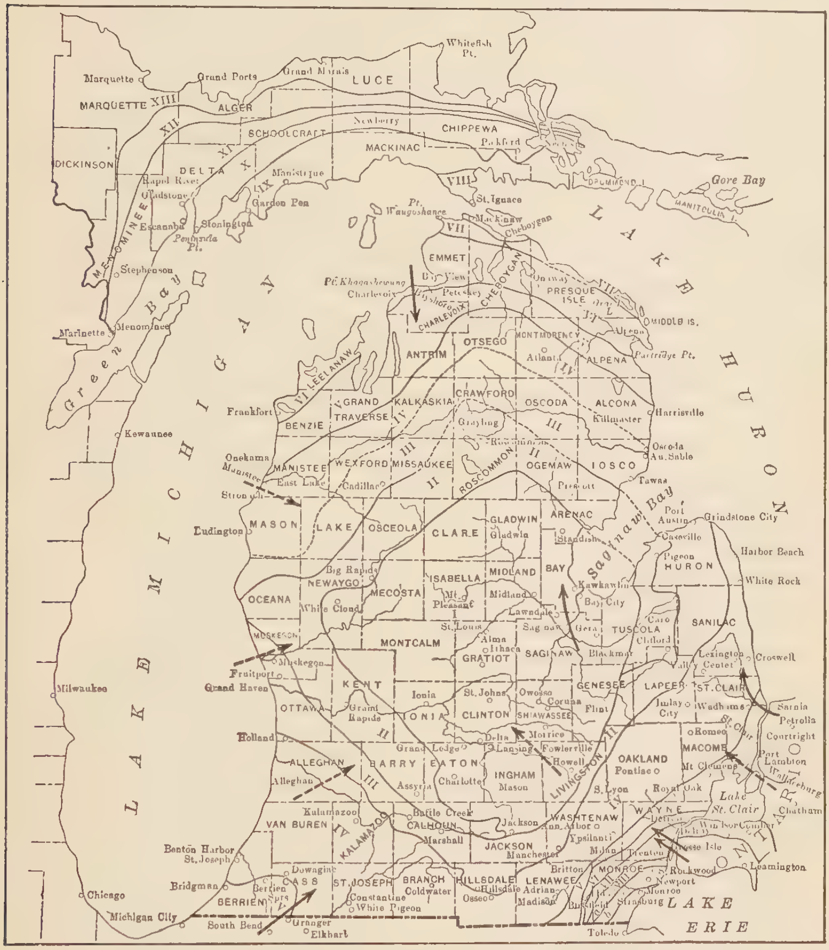

FIG. 118. Outline geological map[1] of Michigan showing Paleozoic formations and the location of deep borings.

Shallow low-pressure gas is found at a number of places in the northern part of the peninsula where the drift is very thick locally and overlies exposures of the Antrim shale. The Antrim and Dundee formations can be traced across southern Michigan[1] by a chain of "shale" or surface gas wells and gas springs. However, while several of the underlying beds are petroliferous at the outcrops, and produce both oil and gas in other fields, drilling has as yet failed to develop production anywhere in Michigan except that cited at Port Huron. An anticline running through Saginaw and Bay County has been tested along its crest for two or three miles near Saginaw, and on its flanks for a greater distance. These wells developed good shows of oil and gas at several horizons. The most promising reservoir encountered, that in the Dundee formation, was irregular in its distribution and porosity.

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[1] Mich. Geol. and Biol. Surv. Pub. 14, Geol. Ser. 11.

It is quite possible that had this well-defined anticline (which is 25 to 30 miles long) been tested further along its crest, the "sand" would have been found more open at some point, and would have shown an oil accumulation.

A reference to the accompanying section (Fig. 119) shows that this entire field is a great spoon-shaped synclinal trough, with its long axis running north and south. Included in the geologic column are the following petroliferous horizons:

(1) Berea sand. In Michigan this is present as a sand only in the southern and eastern sides of the basin. It is usually full of strong brine, but occasionally contains a little gas.

(2) Antrim shale. This is a black carbonaceous shale, with a petroliferous odor, which usually contains gas. There are no continuously porous horizons known in this formation, but possibly local bodies may yet be found.

(3) Traverse shale formation. Dark shales and limestones. Several good oil and gas shows were encountered in this formation in wells drilled at Saginaw.

(4) Dundee ("Corniferous") formation, principally limestone. A porous stratum in this formation is the producing "sand" in Lambton County, Ontario, and Port Huron, Michigan. Unless the sand is saturated with salt water, wells almost invariably get a show of oil in this formation. The best indications in the wells at Saginaw were in this formation.

(5) Niagara. This is the producing formation of the Tilbury-Romney gas fields of Ontario. It has also produced oil, near Fletcher and Chatham.

(6) Clinton-Medina. The principal oil and gas bearing formation in the Erie field in Ohio, New York and Ontario.

(7) Trenton limestone. The oil-bearing formation in the Lima-Indiana fields. It contains hydrocarbons at the outcrops on Manitoulin Island, and elsewhere.

While in general a syncline such as this (Fig. 118) is less favorable for oil or gas accumulations than is an anticlinal structure, and especially as regards "sheet" sands; yet subsidiary folds which occur on the flanks of the main basin can be expected to have retained and prevented considerable oil and gas from migrating further upward. This entrapping may also be accomplished by irregularly shaped porous beds which

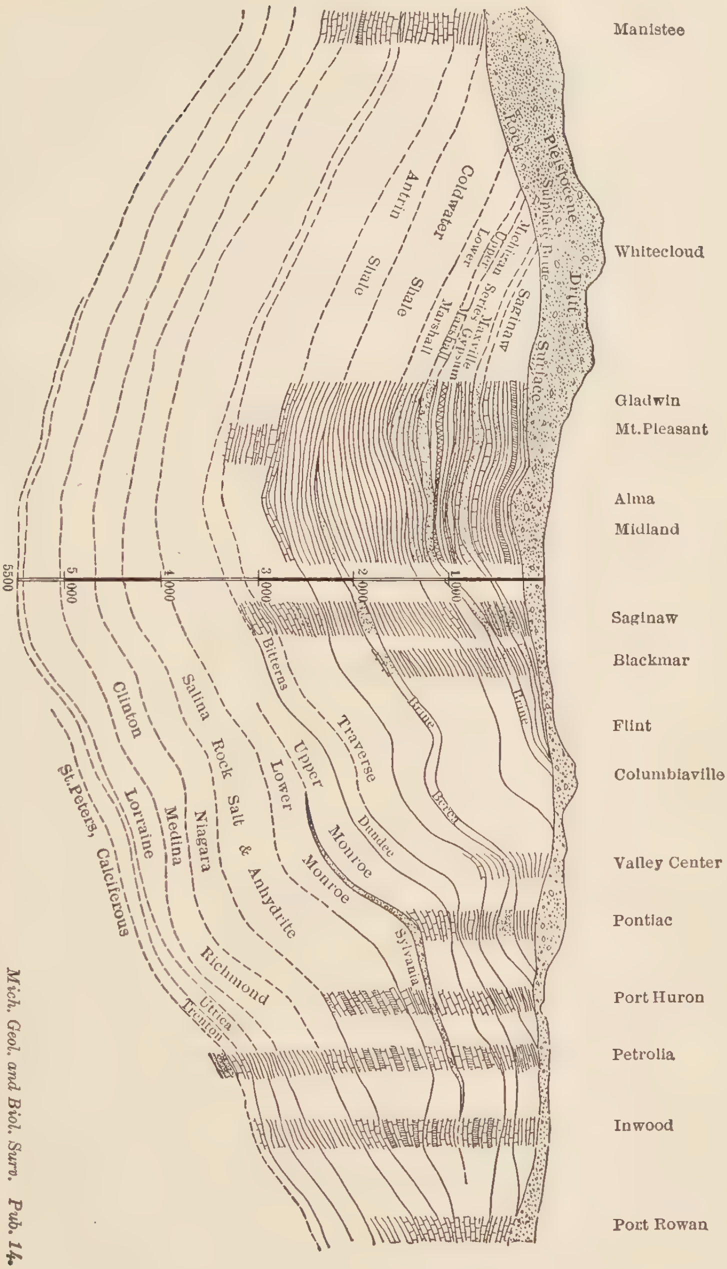

FIG. 119. Diagrammatic cross section of the Michigan Basin from Port Rowan, Ontario, to Manistee, Michigan.

Mich. Geol. and Biol. Surv. Pub. 14.

do not afford a continuous passage for migrating oil or gas. The wells drilled at Saginaw afforded favorable indications of such possibilities.

More or less favorable anticlinal structures are known to exist at several localities on the flanks of the Michigan synclinal basin. R. A. Smith[1] mentions the following:

(1) East of Niles in Berrien and Cass Counties.
(2) Wyandotte, Wayne County.
(3) Port Huron, St. Clair County.
(4) Saginaw and Bay City, Saginaw and Bay Counties.
(5) Allegan, Allegan County.
(6) Muskegon, Muskegon County.
(7) Manistee, Manistee County.
(8) Charlevoix County.

All of the oil and gas formations given in the preceding table contain, within the state of Michigan, oil or gas in some quantity. With the exception of the Port Huron anticline mentioned, the formations on most of the other anticlines have not been well tested, and some of them have never been tested at all. On account of the thick covering of drift on the northern part of the peninsula, all evidence of structure is obscured, but it is quite probable that other favorable localities exist other than those mentioned, and it is to be expected that further prospecting and drilling will bring Michigan into the ranks of the oil-producing states.

The following is the analysis of the oil found in one of the wells drilled at Saginaw, in the Dundee formation:

Gravity 47° B.:	Per cent
Naphtha	28.16
Burning oil	34.5
Intermediate	8.66
Wax distillate	22.8
Tar	3.23
Loss	2.65

The oil produced from the wells at Port Huron is heavier, and similar to that produced at Petrolia in Ontario.

Lima-Indiana Field

The Lima-Indiana field[2] comprises those counties in northwestern Ohio and northeastern Indiana which produce oil from the Trenton limestone. These include Mercer, Shelby, Auglaize, Hancock, Putnam, Van Wert, Allen, Sandusky, Ottawa, Wood, Lucas, Wyandotte, Seneca and Paulding Counties in Ohio, and Adams, Wells, Huntington, Grant, Blackford, Jay, Madison, Delaware and Randolph Counties in Indiana.

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[1] Mich. Geol. and Biol. Surv. Pub. 14, Geol. Series 11.

[2] Blatchley, W. S., The Petroleum Industry of Indiana, 21st Ann. Rept. Indiana State Geol. Surv., 1896.

The development of these fields started with wells drilled at Findlay, Ohio, for gas, in 1884–5, although natural gas was first used in this vicinity as early as 1838. The development in 1885 led to much waste and extravagance in the use of the gas. Many industries grew up around the district for the sake of the cheap fuel. Municipalities such as Findlay, Bowling Green, Tiffin and Fostoria undertook gas prospecting as a municipal enterprise. Then as the supply declined, and new wells came in small and at low pressure, the large factories left, and later the smaller ones, so that by 1891 the industrial boom was well over.

Oil was first found at Findlay in 1886, in a well drilled for gas. It was regarded as a nuisance, particularly as the gravity was low and it contained considerable sulphur. The Frasch copper oxide process of getting rid of the sulphur solved the refining problem, and oil development came on with a rush. The maximum production for these fields, which by that time had spread into the adjoining counties in Indiana, was more than 25,000,000 barrels for the year 1896. Production again in 1905 almost reached this amount, but since that time declined steadily, and in 1914 amounted to less than 5,000,000 barrels (Fig. 107).

The surface rocks throughout this area, and below the drift, are Silurian. The top of the Trenton limestone lies from 1000 to 1600 feet in depth, and the oil and gas pays are encountered in the upper 100 feet of this formation. In some areas the accumulation of oil and gas has been affected by the structure of the formations, while in others the extent of the dolomitization of the limestone has been the determining factor as to the location of the reservoir. The field is remarkable in that it remains the only known instance of a large amount of oil and gas

Blatchley, W. S., The Petroleum Industry of Indiana, 28th Ann. Rept., 1903.

Blatchley, W. S., The Main Trenton Rock Field of Indiana, 31st Ann. Rept., 1906.

Phinney, A. J., Natural Gas Fields of Indiana, U. S. G. S. Ann. Rept. Pt. I, 1889–90.

Orton, E., Econ. Geology, Geol. Surv. of Ohio, Vol. VI, 1888.

Orton, E., Trenton limestone, etc., Ann. Rept., U. S. G. S. 8, 547–662.

Orton, E., Petroleum and Natural Gas in Trenton and Clinton limestones, 1st Ann. Rept., Geol. Surv., Ohio, 1892.

Bownocker, J. A., "Occurrence and Exploitation of Petroleum and Natural Gas in Ohio," Geol. Surv. of Ohio, 4th Ser., Bull. I.

found in rocks as old as the Trenton limestone (Ordovician). It is also one of the largest fields producing from a dolomitic limestone reservoir.

The fields lie along the crest of the Cincinnati and Wabash geanticlines. The shallowness of the wells, the low cost of operating, and the nearness to market and refineries, caused these fields to be developed rapidly and thoroughly. At the present time new drilling is only stimulated when the price of oil reaches a fairly high point. In 1913 the average initial production of all wells drilled was between 13 and 14 barrels per day. There was then an average of from 14 to 15 per cent of dry holes.

The oil is asphaltic, and contains an average of about 0.75 per cent of sulphur. It runs about 37° B. gravity, with approximately 10 per cent of gasoline. A great deal of it is refined locally, while a pipe line takes large quantities to the Standard Oil Refinery at Sarnia, Ontario, for refining; and some is taken by barge to an independent refinery at Wallaceburg, Ontario.

Illinois

A great geosyncline occupies most of the State of Illinois,[1] and extends south-southeast into Indiana and a short distance into Kentucky. At the center of this geosyncline Pennsylvanian rocks are exposed, where not covered by glacial drift. This thick mantle of drift is absent only in the southern part of the state. The oil sands lie in the lowermost Pennsylvanian and the underlying Mississippian, especially in the Chester formation. The principal production has been from pools along the great La Salle anticline, which is surmounted by domes, the most prominent being in Sec. 30, T. 4 N., R. 12 W. The production has been remarkable for the small amount of gas in proportion to the oil, for the very large number of small scattered pools over the anticline, and for the large number of sands that have been productive. Many leases in the field have produced from three sands.

The oil is of an intermediate grade. It carries some asphalt, but only from the limestone reservoirs has the oil sufficient sulphur to demand separate gathering lines and treatment. There has been no discrimination of price either on the basis of gravity nor with reference to the sulphur content.

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[1] Illinois State Geol. Survey, Bull. 2 and 22.

Blatchley, R. S., Structural Relation of the Oil Fields of Crawford and Lawrence Counties, Ill., Econ. Geol. VII, 574–582.

Wheeler, H. A., The Illinois Oil Fields, Trans. A. I. M. E., 1914.

Southward the field extends to the Princeton and Oakland pools in Indiana, and some of the later activity has been on the southern end near St. Francisville.

Deep drilling to the Trenton on the La Salle anticline has given some small wells, but not enough to encourage continued development. Nevertheless, since the outcrop of the Trenton in other parts of the state shows some oil, a Trenton field may be looked for either further north on the La Salle anticline, or in other parts of the state.

On the westward side of the basin[1] there is no great dominating anticline, and the development there lies in scattered pools, inasmuch as the structural features are small and scattered. There has been production at Sandoval, Sparta and Carlyle, in Mississippian sands. The most prominent anticline of all, the Duquoin, has yielded nothing of commercial importance in the tests so far drilled, possibly because it is faulted.

The Niagara limestone having shown oil at its outcrop near Chicago has been looked upon as a promising horizon for years, and has now given production in the pools near Plymouth, Illinois.

The St. Peter sandstone underlies much of the state, but most of it is now too deep for the drill. While so far it has always yielded water only, the occurrence of oil and gas in what seems to be the Burgen sandstone, a correlative in Oklahoma, makes it a possible if not a probable contributor.

But the field on the La Salle anticline is by no means to be considered a completed field. Whenever we have reservoirs of such limited extent, we are sure to find others extending far down the dip. We have here no such condition as in the Salt Creek Dome in Wyoming, where there is a distinct water line surrounding the dome.

Technologically,[2] Illinois offers no especial problems of importance. The relatively flat topography has made the operation of wells easy, so that an unprecedented proportion of wells are pumped by shackle-lines from powers.

An interesting feature has been the very great retardation in development, attributable mainly to failure to case off water in some of the early tests. So that while wells drilled in 1865 should have started development, the early "wet" method of drilling with a hole full of water prevented the detection of the oil present.

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[1] Ill. State Geol. Surv. Bull. 16.

[2] Blatchley, R. S., Drilling for Oil in Eastern Illinois, Min. and Sci. Pr., Nov. 6 and 20, 1909.

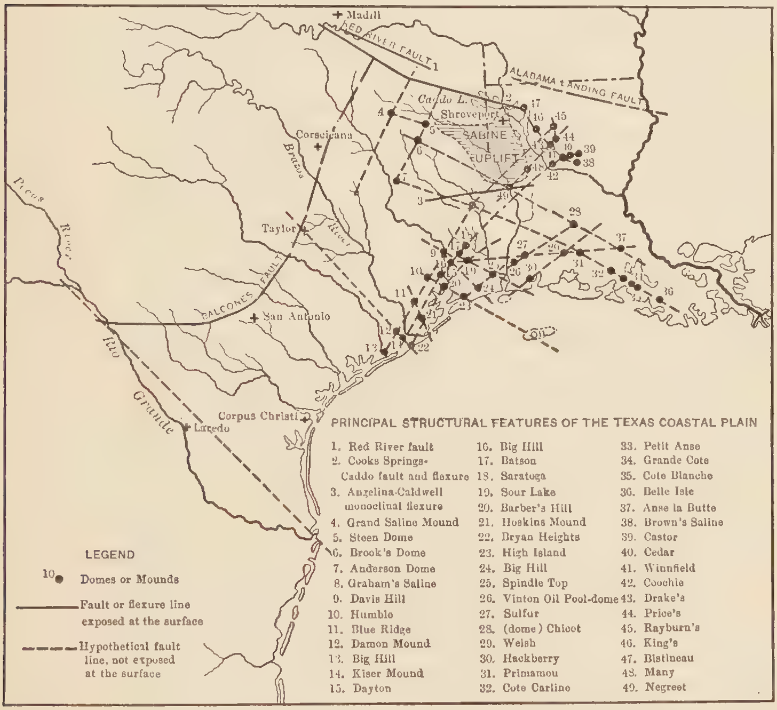
THE MARKETED PRODUCTION OF PETROLEUM IN THE ILLINOIS FIELD FROM 1889 TO 1913.

Year.	Production, barrels.	Value.	Yearly average, price per barrel.	Producing wells.
1889	1,460	$4,906	$3.360	....
1890	900	3,000	3.333	....
1891	675	2,363	3.500	....
1892	521	1,823	3.500	....
1893	400	1,400	3.500	....
1894	300	1,800	6.000	....
1895	200	1,200	6.000	....
1896	250	1,250	5.000	....
1897	500	2,000	4.000	....
1898	360	1,800	5.000	....
1899	360	1,800	5.000	....
1900	200	1,000	5.000	....
1901	250	1,250	5.000	....
1902	200	1,000	5.000	....
1903	....	....	....	....
1904	....	....	....	....
1905	181,084	116,561	0.644	189
1906	4,397,050	3,274,818	0.745	3,093
1907	24,281,973	16,432,947	0.677	7,353
1908	33,686,238	22,649,561	0.672	10,372
1909	30,898,339	19,788,864	0.640	11,152
1910	33,143,362	19,669,383	0.593	12,171
1911	31,317,038	19,734,339	0.630	12,753
1912	28,601,308	24,332,605	0.851	13,222
1913	23,893,899	30,971,910	1.296	14,100
1914	21,919,749	25,426,179	1.160	14,800
1915	18,500,000 est.	....	....	....
	250,826,616	$182,423,759		

Gulf Coast Field

The Gulf Coast field is the term used to describe those oil and gas pools which occur along the coast of the Gulf of Mexico and extend from the Mississippi River to the Sota la Marina in Mexico. Nearly all the pools which have been developed in this belt have been of the saline dome type, in which the oil has been found concentrated around cores of salt, gypsum and sometimes sulphur. More recently gas wells have been drilled in the vicinity of Corpus Christi and Laredo, where the pay formations are relatively undisturbed Tertiary sands, of approximately the same age, however, as those surrounding the salt domes at the horizon where the oil is found.

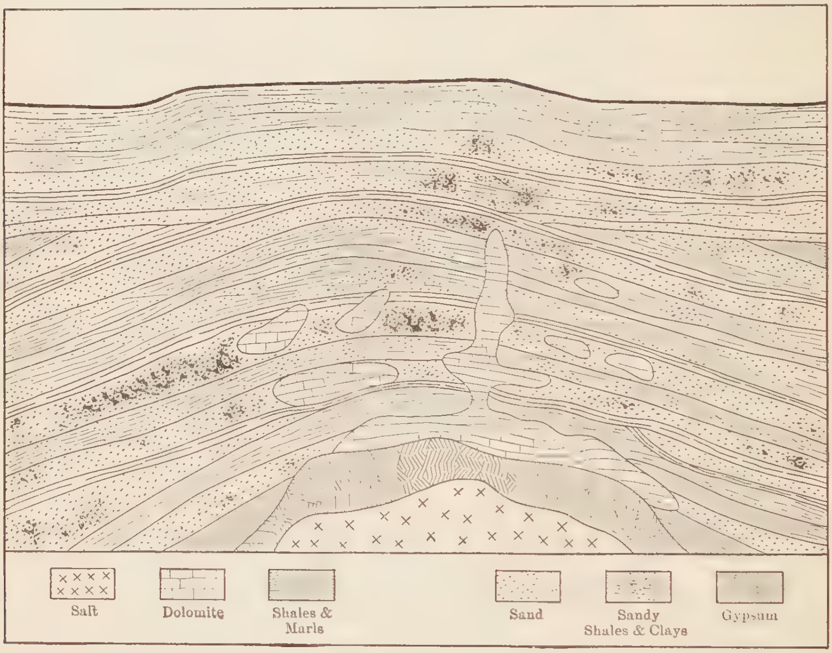
Oil was first discovered in these fields south of Beaumont in a well drilled January, 1901, by Captain A. F. Lucas for the Guffey interests. Its initial production was about 75,000 barrels per day. This led to the search for similar locations, and among the most important of these pools which have since been developed are those at Anse la Butte, Jennings, Welch and Vinton in Louisiana, and Sour Lake, Big Hill, Humble, Saratoga and High Island in Texas. Production from these fields reached a maximum of approximately 37,000,000 barrels in 1905, but had fallen off to less than 9,000,000 barrels for the year of 1913, in spite of the discovery of several new pools and the extension of the limits and depths of old ones. The production since has increased spasmodically. During 1914 several large gas wells, some of which showed signs of oil, were drilled in the vicinity of Corpus Christi.



After Harris and others.

FIG. 120. The broken line along the Rio Grande River is not a fault, but the line of the section shown in Fig. 122.

With the exception of Corpus Christi and Laredo districts, all the pools which have been developed in coastal Texas and southern Louisiana are located along a series of hypothetical, intersecting fault lines (Fig. 120). Such intersections are thought to have afforded courses for the circulation of underground waters, which have deposited in many of them cores of rock salt, gypsum, sulphur and secondary limestone and sinter. All of these domes are not oil-bearing, and in at least one (that at Sulphur, Louisiana) the sulphur deposit is of more commercial importance than is the oil found. The sedimentary beds are bent upward from all sides around these domes, and faulting is known to exist in the vicinity of some of them.



After Lee Hager.

Fig. 121. Vertical section through a Gulf Coast salt dome.

Geologists differ as to whether the oil found in these domes had its origin in deep-lying Mesozoic or even Paleozoic beds, or whether it came from the formations surrounding the horizons at which it is now found. These latter range from Quaternary sands down to the Jackson beds of the upper Eocene (Tertiary). Certainly, from what we know of the older formations which underlie this region, conditions at the time of their deposition were more favorable for the deposition of petroleum-forming material than was the case when the later Tertiary beds were deposited. The Cretaceous of northern Texas and Louisiana, and the Carboniferous of Oklahoma and Texas, have yielded large pools; and the outcrops of these beds yield confirmatory evidence as to their petroliferous character. However, in the Eocene formations, the marine beds above the Midway and Wilcox formations have yielded a little oil at Oil Center in Nacogdoches County, and at Crowther in McMullen County; and the Yegue formation has proved a valuable gas producer in the Gulf Coast region between the Brazos and Rio Grande, notably in the Corpus Christi district.

Harris believes that crystallization is the force which caused this doming of the strata; but Norton offers a more plausible explanation when he suggests that these domes represented mineral springs which deposited their salts at the surface contemporaneously with the surrounding sediments. Then, as compacting and subsidence took place, the strata sagged away from such harder cores, while at the same time concentration of the oil took place by circulation along bedding planes and faults. Undoubtedly such intersecting faults, kept open by channeled secondary deposits of salt and gypsum, would be expected to furnish a reservoir for the accumulation of oil. This view is borne out by the fact that many beds which underlie the surrounding areas are lacking or are very thin in the vicinity of these domes.

In general this region[1] represents a great

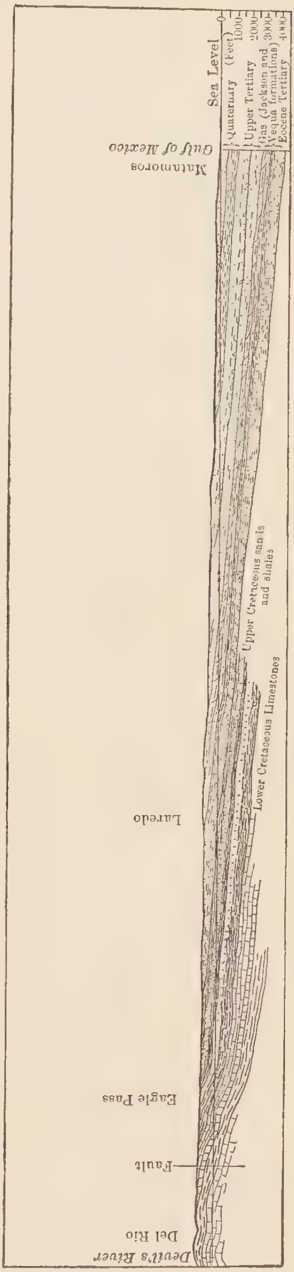


FIG. 122. Section along the Rio Grande from Del Rio to the Gulf of Mexico.

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[1] Louisiana State Geol. Surv. Bulletins 7 and 8.
Norton, Edw. G., The Origin of the Louisiana and East Texas Salines, Bull. A. I. M. E., Jan., 1915.
Duessen, A., U. S. G. S. Water Supply Paper 335.
Hayes, C. W. and Kennedy, W., U. S. G. S. Bull. 212.
Harris, G. D., U. S. G. S. Bull. 429.
Harris, G. D., Econ. Geol., 1909, Vol. IV, pp. 12–34.
Emmons, S. F. and Hayes, G. W., U. S. G. S. Bull. 213, pp. 345–352.

homocline (Fig. 122) dipping toward the Gulf of Mexico. However, a number of broad flexures are known, among which Harris mentions the one at Jennings and Five Islands. Sedimentary gradients may also have caused oil and gas accumulations of relatively small extent throughout this region. The authors believe, however, that the following hypotheses are, from the present evidence, the most usable:

(1) Apparently the most favorable beds in the Tertiary are the Fleming Group of the upper Tertiary, and the Jackson, Yegua (possibly), and the marine shales of the Eocene. Some of these probably become more favorable at greater depths to the South.

(2) That while probably some of the oil found in the saline dome pools has migrated from the relatively more petroliferous Mesozoic and even Paleozoic formations below, yet conditions around such cores are so favorable for the concentration of oil along bedding planes, that the relatively poorer oil horizons in the Tertiary would yield large aggregate amounts to such reservoirs.

In the Mexican fields the poor upper Tertiary formations at Tierra Amarilla have given secondary accumulations of oil rising along fractures and intrusions from reservoirs in the lower Cretaceous.

(3) That these Tertiary formations will continue to yield large amounts of gas at certain localities, and particularly where well marked folds occur.

(4) That while small pools will be developed from time to time throughout the coastal plain underlain by Tertiary formations, yet in general these formations are more favorable for oil in saline domes.

(5) That prospecting may be expected to develop dome structures with large oil production at points between the Brazos River and the Sota la Marina in Mexico.

Wyoming

The oil fields of Wyoming[1] are so separated by the very complicated structure of the state that they do not constitute one natural field. It is largely for convenience that they are grouped together. The prospects and pools which have been worked or written about may be classified as follows:

Field	*County*
Black Hills Border Fields:	
(1) Moorcroft	Crook
(2) Upton	Weston
(3) Newcastle	Weston
Big Horn Basin:	
(4) Elk Basin	Big Horn
(5) Byron	Big Horn
(6) Greybull	Big Horn

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[1] Trumbull, L. W., Light Oil Fields of Wyoming. State of Wyoming, Geologist's office, Bull. 12.

Ball, Max W., Petroleum Withdrawals and Restorations, U. S. Geol. Survey Bull. 623.

Field	*County*
(7) Basin	Big Horn
(8) Bonanza	Big Horn
(9) Cottonwood	Washakie
(10) Grass Creek	Hot Springs
(11) Little Buffalo	Park and Hot Springs
(12) Oregon Basin	Park
(13) Cody	Park
Eastern Wyoming:	
(14) Buck Creek	Niobrara
(15) Douglas	Natrona
Central Wyoming:	
(16) Salt Creek	Natrona
(17) Powder River	Natrona and Johnson
(18) Muddy Dome	Converse and Natrona
(19) Rattlesnake	Natrona
(20) Arago	Natrona
(21) Dutton	Fremont
(22) Oil Mountain	Natrona
Southern Wyoming:	
(23) Muddy Creek	Carbon
(24) Lost Soldier	Carbon
(25) Rock Springs Dome	Sweetwater
(26) Lander	Fremont
(27) Dallas	Fremont
(28) Pilot	Fremont
Southwestern Wyoming:	
(29) Spring Valley	Uinta
(30) Labarge	Lincoln

Of these, the Salt Creek and Grass Creek far exceed the others in importance. The production of Wyoming has been as follows:

PRODUCTION OF WYOMING

Year.	Quantity.	Value per barrel.	Remarks.
1894	2,369	6.720	Shannon opened.
1895	3,455	8.000	
1896	2,878	8.000	
1897	3,650	8.000	
1898	5,475	7.000	
1899	5,560	7.000	
1900	5,450	7.000	
1901	5,400	7.000	Spring Valley opened.
1902	6,253	7.000	
1903	8,960	7.000	
1904	11,542	7.000	Douglas opened.
1905	8,454	6.100	
1906	(*a*) 7,000	7.000	
1907	(*b*) 9,339	2.343	Byron opened.
1908	(*b*) 17,775	1.570	
1909	(*b*) 20,056	1.718	
1910	(*b*) 115,430	0.810	
1911	(*b*) 186,695	0.664	Salt Creek dome opened.
1912	1,572,306	0.507	
1913	2,406,522	0.493	
1914	3,560,375	0.472	Grass Creek opened.
1915	(*a*) 4,200,000	......	

(*a*) Estimated. (*b*) Includes Utah.

Newcastle. — The Newcastle[1] field received attention very early in the history of Wyoming oil development, a well being drilled in 1890. Enough oil has been found to keep up a fluctuating activity, but there is no regular production at present (1915).

The Graneros formation (a subdivision of the Benton) outcrops here, having been brought up by the Black Hills uplift. Denudation has exposed an enclosed sandstone lens which yields oil along the outcrop at favored spots. Naturally the oil is heavy (22.8° B.) because of the outcropping sand. It is, however, free from asphalt. A remarkable feature of this field is the fact that the wells have nearly all been started near the outcrop and then drilled far on past the oil sand, in some cases the operator apparently failing to recognize the shallow sand found as the one that was sought. On the other hand, in a few cases wells were started too far down the dip to catch the sand in the depth drilled.

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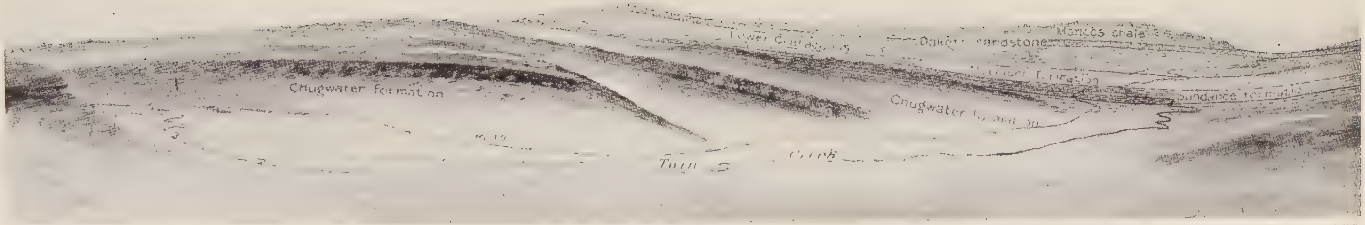
[1] Knight, W. C. and Slosson, E. E., The Newcastle Oil Field, Univ. Wyoming, School of Mines, Petroleum Ser., Bull. 5.



U. S. Geol. Surv. *Bull. 452, Plate III.*

FIG. 123. Diagram showing structure and stratigraphy of anticline in Little Popo Agie District, Wyoming.

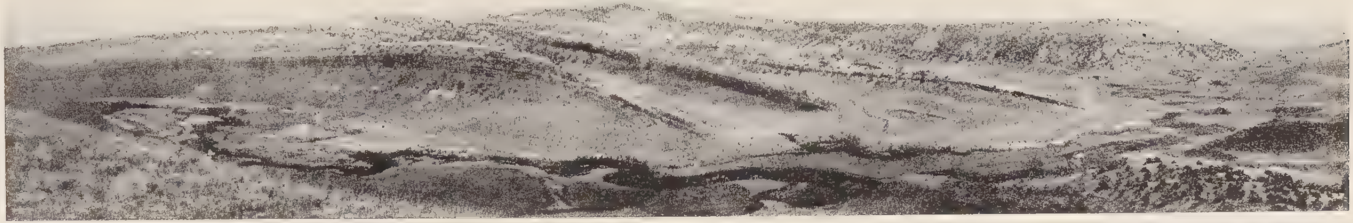


FIG. 124. View of anticline in Little Popo Agie District. Lander Oil Field, looking northwest across Twin Creek.

Upton. — While the Upton dome is here classified as a Black Hills border field, it lies far enough from the outcrops of the oil-bearing beds so that the pertinent feature is the dome rather than the outcrop. On the dome the Lower Graneros is the oldest exposed bed, and thus the possibilities of the dome are much limited. There is still the possibility of production in the Dakota, which Trumbull estimates to be only 220 feet deep. The dips are 10 degrees and 11½ degrees respectively. It is certainly worthy of a test, since though it might fail to yield oil or gas, a paying water well may be expected.

Moorcroft. — The Moorcroft field[1] (formerly the Belle Fourche) is similar to the New Castle in most respects. The first well was drilled in 1888. In spite of the existence of oil springs and the drilling of 41 wells and 21 shallow holes no commercial production has resulted. The columnar section given on p. 299 by V. H. Barnett[2] will suffice also for Newcastle and Upton.

The Moorcroft field has seepages from a sandstone in the Fuson shale, the Dakota sandstone, and a sandstone in the Graneros formation. There is a well-marked anticline culminating in a north and south dome. On these domes the Dakota has been completely worn away, and in the connecting anticline the Dakota is exposed. Wells on these domes could only serve to test the Paleozoic formations, which, if one judges from the Black Hills exposures, seem less promising than the Cretaceous. But the Moorcroft activities have been in the main part efforts to obtain production from an oil sand in the Graneros formation down the dip from the outcrop. The results, as so often in the Rocky Mountain fields, are disappointing, since success is seldom obtained here unless the sand is domed and yet under cover, or if the sand is on a homocline then it is in a different reservoir than that exposed at the outcrop. Development would seem to be more worth while down the dip where there is favorable structure. The looped contour southwest of Edgemont in Darton's map may indicate a dome. A more detailed examination of it and of the Blacktail and Pine Ridge anticlines, discussed in the section on the Northwestern Plains, would be desirable.

Big Horn Basin. — The Big Horn Basin has an unusually interesting series of domes with productive beds at convenient depths around its edges. These are well shown in the comprehensive isobath map of

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[1] Trumbull, L. W., A Report on the Moorcroft Oil Field, Bull. of the State Geologist of Wyoming. In press.

[2] Barnett, V. H., The Moorcroft Oil Field, Crook County, Wyoming.

GENERALIZED SECTION OF ROCKS IN THE MOORCROFT OIL FIELD, WYO.

System.	Series.	Group.	Formation.	Character.	Thickness. Feet.	Character of topography and soil.
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Friable sandstone and sandy shale.		Rolling hills and rounded ridges; sandy soil with good grass.
			Pierre shale.	Dark shale with calcareous concretions.	2000	Wide plains with shallow valleys thin, clayey, and not very fertile soil, supporting fair growth of grass.
		Colorado.	Niobrara shale.	Gray calcareous shale.	100	Shale slopes; limy soil.
			Carlile shale.	Gray shale with oval concretions and thin sandstones.	500	Rolling hills with thin clay soil, mostly covered with grass.
			Greenhorn formation.	Shale with impure concretionary limestone.	175	Small bare ridges.
			Graneros shale.	Black shale with concretions. Hard gray shale containing many fish scales (Mowry shale member). Sandstone, oil bearing. Black shale with small concretions.	1245	Wide valleys containing extensive alluvial deposits. Shaly ridges, partly wooded Valleys with clay soil and badlands.
			Dakota sandstone.	Gray to buff sandstone, mostly very massive; weathers reddish brown.	5 +	Plateaus, canons, and high cliffs with rocky slopes; thin sandy soil.
	Lower Cretaceous.		Fuson shale.	Shale and sandy shale with local sandstone.	70	Slopes below cliffs of Dakota sandstone.
			Lakota sandstone.	Light-colored coarse massive sandstone.	25–50	Canons with cliffs; thin sandy soil.
Jurassic or Cretaceous.			Morrison shale.	Massive pale greenish-gray to maroon shale with limestone nodules.	125±	Steep slopes below cliffs of Lakota sandstone; poor soil.

Fisher.[1] Some of the lesser ones not individually discussed in the following pages are mapped in more detail by Fisher, Washburne[2] and Woodruff.[3]

The stratigraphy as given by Hintze is tabulated on p. 301.

As will presently appear, the Cloverly and Benton are the most promising horizons. It is, therefore, disappointing to find that erosion has worn down a number of the domes to the Morrison or Sundance formation. While such domes are not worth attention yet, they may deserve testing in future years, since the underlying Embar limestone has shown oil on the Popo Agie anticline, a small amount in a well near Spence, and Johnson reports some in Box Elder Creek. There is also the asphalt deposit in T. 52, R. 90 W. reported by Peary, and thought by Washburne to be from the Pennsylvanian. The Madison limestone still deeper is reported to have shown an oil seepage in Sheep Canon.

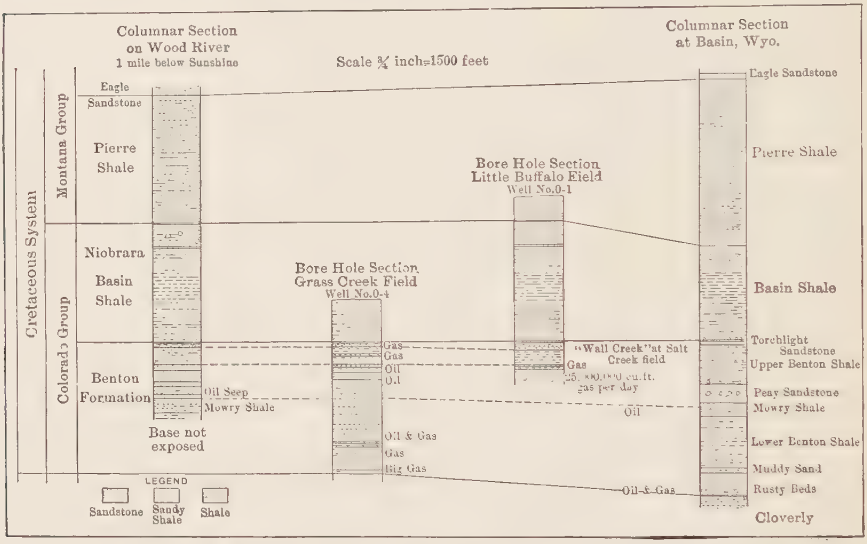

FIG. 125. Columnar sections in the Big Horn Basin oil and gas fields. (By Hintze.)

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[1] Fisher, C. A., Geol. and Water Resources of the Big Horn Basin, Wyo., U. S. G. S. Prof. Paper 53.

[2] Washburne, C. W., Gas Fields of the Big Horn Basin, Wyo., U. S. G. S. Bull. 340, pp. 348–363.

Washburne, C. W., Coal Fields of the Northeast Side of the Big Horn Basin, Wyo., U. S. G. S. Bull. 341, pp. 165–199.

[3] Woodruff, E. G., Coal Fields of the Southwest Side of the Big Horn Basin, Wyo., U. S. G. S. Bull. 341, pp. 200–219.

Table of Formations in the Big Horn Basin, Wyo. (F. F. Hintze.)

System.	Group.	Stage or formation.	Thickness in feet.	Characteristics.
Lower Eocene		Fort Union	1000 to 2000	Massive sandstone and dark-colored shale, with coal.
Upper Cretaceous		Ilo	150 to 700	Massive sandstone with some shale, also coal-bearing.
	Montana	Undifferentiated Montana	850 to 1000	Dark-colored shales and massive buff and brown sandstone.
		Eagle sandstone	400	Massive fresh and brackish water sandstones and shales, coal-bearing.
		Pierre shale	1600 to 1800	Alternating light and dark marine shales, lighter colored beds often sandy. Lower third fossiliferous.
	Colorado	Basin shale	900 to 1000	Marine shales, dark-colored, weathering into bad-land forms, containing calcareous concretions and many fossils in upper half. Large brown sandy concretions at base, highly fossiliferous.
		DISCONFORMITY		
		Torchlight sandstone	20 to 30	Light gray, often white, saccharoidal sandstone, often strongly cross-bedded. Always capped by a layer of black and gray pebbles, poorly cemented together.
		Upper Benton shale	350 to 400	Black adobe shale and sandy shales, and Bentonite.
		DISCONFORMITY		
		Peay sandstone	150 to 200	Light gray and light brown sandstone, with large sandy concretions in central part. Top layer conglomeratic.
Upper Cretaceous	Colorado	Lower Benton shale	850 to 900	Hard blue sandy shale (Mowry) near the top, underlain by black adobe shale and thin layers of bentonite. White saccharoidal sandstone 25 to 40 ft. thick near the central part. Lower 75 to 125 ft. light brown and yellow sandy shale, the "Rusty Beds."
		DISCONFORMITY		
Lower Cretaceous		Cloverly	75 to 125	Bright-colored clays and argillaceous sandstones, with massive sandstones at the top and bottom. Upper layer sometimes wanting.
Lower Cretaceous or(?) Jurassic		Morrison	250 to 350	Bright variegated, terrestrial, clays and soft sandstones.

Elk Basin. — This is the northernmost of the several anticlines along the east side of the Big Horn Basin. It straddles the Montana-Wyoming line. Numerous faults cast some discredit upon it and this, with its distance from the railroad, has delayed its testing. Oil has now been obtained and the pool is in a state of active development.

Byron. — Of the several anticlines mapped by Washburne north of Greybull, the Byron was the first to become commercially productive. The oil is of good quality, and is piped to a small refinery at Cowley. The productive wells are limited to a small area on the flank of the anticline. The reservoir is composed of fissured shale at the horizon, approximately, of the Mowry shale. Recently a very large gas well has been completed.

Greybull. — At Greybull the Peay Hill Dome is productive of gas from an horizon considered by Hintze to be the Cloverly. Owing to an inexcusable waste of gas from the discovery well, the pressure is now much reduced. Since the oil is found so far down the west flank of the dome, and as yet not on the other sides, the productive sand is probably lenticular. The oil is refined at Greybull, and is from 40° to 49° B. and is free from asphalt.

The Crescent anticline extends some distance to the southeast from the dome. It is not as yet productive.

Basin. — East of Basin lie two domes, both of which are productive of oil from the Kimball sand, an horizon higher than that at Greybull. Hintze[1] places it in the Mowry formation. There are thus far several gas wells but only one productive oil well (28° B.) on the Lamb anticline, but on the Torchlight[2] anticline operations have been so successful as to lead to the building of a pipe line to the Greybull refinery. There is little gas from this dome, and the oil is of 46° B.

Bonanza. — An oil spring near Bonanza led to operations as long ago as 1884, when the railroad was 80 miles away. The oil is from a sandstone just below the Mowry shale. There has been no commercial production. The anticline shows dips of 45 degrees and 13 degrees on its flanks. The axis rises to the southeast where the beds exposed at the center of a dome are said by Knight[3] to be Shirley (Jurassic).

Cottonwood Dome. — There is a dome with dips of 19° and 26° on the south flank, and 7° to 15° on the north flank. This dome is thought to lie in the south half of T. 47, R. 90. There are three oil springs near the center. The horizon here was thought by Knight to be most probably the Pierre. This does not seem to have been prospected as yet, but is well worthy of investigation.

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[1] Hintze, F. F., Jr., Basin and Greybull Oil and Gas Fields, Wyoming, State Geol. Survey, Bull. 10.

[2] Lupton, C. T., Oil and Gas near Basin, Big Horn Co., Wyo., U. S. G. S., Bull. 621.

[3] Knight, W. C., Bonanza, Cottonwood and Douglas Oil Fields, Sch. of Min. Univ., Wyo., Bull. Pet. Ser. No. 6.

Grass Creek Dome. — This very striking dome was well shown by Fisher in 1906. While this and the Little Buffalo Dome have been wistfully considered by several geologists from that time, the difficulties of transportation and titles have prevented their development until 1914. These difficulties still remain, and there is a probability that much of the development has a defective title. The Wyoming State Geologist has given us a prompt bulletin[1] on the field, with an isobath map of the main[2] dome.

The bed exposed at the center of the dome is the Basin shale (Niobrara). Sands in the underlying Benton productive of either oil or gas have been numerous, so that a fairly large area may be expected to be productive in one sand or another.

Fig. 125 shows the correlation of the sands here with some of the other Big Horn sections. The oil is 45° B. and a pipe line has already been built to the railroad and shipments begun.

Little Buffalo Dome. — Between the Grass Creek Dome and Meeteetze, there is a double dome enclosed by a rim of Eagle sandstone.

These domes resemble in many ways the Grass Creek domes. Here also the Basin shales are the lowest beds exposed, but since it is much thicker here, deeper drilling has been necessary to reach the productive horizons in the Benton sandstones. Very large volumes of gas have been found in the Benton in the three wells drilled. There is little doubt but that more and deeper drilling will give a production of oil rivaling that of the Grass Creek Dome.

Fisher indicates three other smaller domes worthy of attention to the west or southwest of this field, in which the Cloverly at least is not exposed.

Oregon Basin. — The Oregon Basin differs from the other domes in that the syncline on its up-dip side is shallow, making it less favorable than the two great domes in the southern part of the Basin. One well is reported to have found gas, however, and oil production may be expected upon this dome, which is within a fair distance from Cody, Wyo. This anticline appears in Fisher's map already referred to, and in the Oregon Basin topographic sheet,[1] as it is nearly surrounded by a prominent sandstone escarpment.

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[1] Hintze, F. F., Jr., Grass Creek Gas Field, State of Wyoming Geologist's Office, Bull. 11, Pt. 2.

[2] For the smaller adjoining dome to the northwest, see the U. S. G. S. topographic sheet for the Ilo quadrangle, and Petroleum Age for March, 1915, p. 5.

Hintze, F. F., Jr., Little Buffalo Basin Oil and Gas Field, State of Wyoming Geologist's Office, Bull. 11, Pt. 1.

Cody. — The Shoshone River, to the east of Cody, shows in its steep bank a cross section [2] of two anticlines. The more prominent of these is called the Shoshone, and is three miles east of Cody. A well was started in 1909 and has produced some oil, but not enough to lead to a successful pool. The production came from about the horizon of the Mowry shale. Gas was also obtained in the Cloverly formation. One unpromising feature of this well is the strong southerly plunge of the anticline. Because of this plunge, the productive horizons outcrop to the north, without an intervening syncline. There is much less promise of development near Cody than in the Oregon Basin, 15 miles to the south.

Buck Creek. — We pass now from the Big Horn Basin to the Buck Creek Flats, where drilling has been undertaken in Section 31 T. 35, R. 64 W. There is some evidence of an anticline in the Pierre shales at the surface. An overlap of the Tertiary from the south makes it difficult to determine a good deal of the structure definitely. This area has been described by Trumbull.[3]

Douglas. — Southeast of Douglas lies the Brenning oil field, where 66 wells have been drilled, yet there is no regular production. The oil at its best is 35.9° B., with 8 per cent of naphtha and no asphalt. The oil is found either in (*a*) the Benton shale or one of its interbedded sandstones, or (*b*) in the basal sandstone of the overlapping White River (Tertiary) formation.

One of the greatest difficulties of the field is the obscuring of its structure by this overlapping. The underlying formation, from what little evidence there is, dips to the north about 30 degrees on the average. Jamison [4] postulates a hidden anticline upon the evidence of a linear group of gas wells. This is not conclusive. There are also some post-White River faults.[5] Judging from its geological promise, the field has received undue attention in comparison with the many more promising ones in Wyoming. This has been principally the result of the proximity of the field to one of the older railroads.

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[1] U. S. G. S. Oregon Basin topographic sheet.

[2] Hewett, D. F., The Shoshone River Section, Wyoming, U. S. G. S. Bull. 541, pp. 89–114.

[3] Trumbull, L. W., Productive Oil Fields at Upton, Buck Creek, etc., Wyo. State Geol. Survey Bull. 5.

[4] Jamison, C. E., Douglas Oil Field, State Geologist of Wyoming, Bull. 3A.

[5] Barnett, B. H., The Douglas Oil and Gas Field, U. S. G. S. Bull. 541, pp. 49–88.

South of Douglas the La Boute[1] field has also led to no commercial production. This field is on the flank of the Phillips dome, with Red Beds outcropping at the center. As the shows obtained were said to have been in the Benton, the field is a homoclinal one. When higher prices stimulate testing the various domes for the underlying Carboniferous, this dome should receive attention.

Salt Creek.[2] — Oil was found in the Shannon field on the flank of the Salt Creek Dome in 1889. Oil was actually hauled 50 miles by wagon to the railroad for many years. This oil was found in the Shannon sand, which outcrops only one and one-half miles from the pool, so that the accumulation is homoclinal rather than anticlinal. It is stated that an Italian geologist, in going from Casper to Shannon to examine the properties for a prospective foreign purchaser, concluded it would be much more worth while to drill on the Salt Creek Dome itself for deeper sands. Knight had previously hinted at the chances in these lower sands. The result was the opening of the large production which has made this the leading pool in the state. This production is from the Wall Creek sandstone, a bed within the Benton shales. This bed seems to be a sheet sand, since all the wells within a definite water line have been productive, and down-dip from this the sand has carried water. So far as known at the present time, none of the wells have been carried any deeper. The chances for success by such deepening are bright, as the Dakota sandstone carries oil at its outcrop in the Powder River Dome to the west. There is also the possibility of obtaining production in sandstones deeper in the Benton. In addition to the horizons just discussed, oil has been obtained from fissured shale reservoirs down the flank of the dip. These wells have been much more successful than might have been supposed, but are of course erratic and difficult to follow up. To the southeast of the main dome, there is a smaller double dome, "The Teapot," which is very promising, but it has been withdrawn as a Naval Oil Reserve.

Powder River Dome. — This dome[3] which is west of the Salt Creek

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[1] Knight, W. C., Bonanza, Cottonwood and Douglas Oil Fields, School of Mines, University Wyoming, Bull. 6.

[2] Knight, W. C., The Petroleum of Salt Creek, Wyo., Sch. of Min. Univ. Wyo. Pet. Ser. Bull. 1.

Jamison, C. E., The Salt Creek Oil Field, Bull. State Geologist, Ser. B., Bull. 4.

Trumbull, L. W., Salt Creek Oil Field, State Geol. Bull. 8, Ser. B.

Wegemann, C. H., The Salt Creek Oil Field, U. S. G. S., Bull. 452, pp. 37–83.

[3] Knight, W. C., The Rattlesnake, Arago, Dutton, Oil Mountain and Powder River Oil Fields, Sch. of Min. Univ. Wyo., Bull. 4.

Dome is unfortunately eroded down to the Sundance formation. Drilling at the crest then would give only a bare chance of success in the Embar and Madison formations, which are less promising. Wegemann[1] suggests that the oil found at the crest in the Sundance and Morrison formations may have arisen from the Embar formation.

To develop the Dakota, it would be much better to move down the dip to the Salt Creek Dome and test it there. If the Dakota is lenticular, future drilling might pay in search of such pools in the intervening district. Shallow drilling close to the outcrop to tap the sealed-in reservoir could only be expected to give small yields of heavy oil.

To drill down the dip from the outcrop of the Wall Creek sandstone on this dome would not seem advisable, since the sandstone in the adjoining Salt Creek Dome acts as a sheet sand. The chance, therefore, of striking a productive lens is very small.

Dutton. — An anticline by this name in T. 34 N., R. 90 W., with dips of from 15 to 50 degrees, plunges strongly to the north, and to the south is overlapped by the Tertiary. The Jurassic is the lowest bed exposed. Oil sands are found in what Knight[2] considered Dakota and Niobrara. Oil was also found in one of the Tertiary beds, and this he believes to be derived from the overlapped Cretaceous.

Oil Mountain. — An anticline in T. 32 and 33 N., R. 82 W. is called Oil Mountain, from an old oil spring. This is on one of two faults in the Fox Hills beds. Knight[3] believes the oil arises from the Dakota. The crest of the fold is southeast of the spring and exposes the Jurassic. The fold is symmetrical, with dips of from 30 to 40 degrees. No prospecting had been done at the time of Knight's report. Following the anticline to the southeast, beyond a saddle, the fold again becomes steeper, giving an exposure of Triassic where it is cut by the North Platte River in T. 32 N., R. 81 W.

Rattlesnake Mountains. — This field[4] is made up of a homoclinal fault block in T. 32 and 33 N., R. 87 and 88 W. The Cretaceous beds dip to the north at an angle of about 30 degrees, where they are overlapped by Tertiary. Several oil springs are found at the outcrop of beds thought by Knight to be Dakota, Benton and Mesa Verde. The Arago field referred to by Knight is merely the southwestern end of the same fault block, and presents the same conditions. With this steep dip and no favorable anticlines, only a small production would probably be available.

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[1] Wegemann, C. H., The Powder River Oil Field, Wyo., U. S. G. S. Bull. 471A, pp. 52–71.

[2] Knight, W. C., "The Dutton, et al., Oil Fields," Sch. of Min., Univ. Wyo., Bull. No. 4.

[3] Knight, W. C., The Oil Mountain, et al., Oil Fields, Sch. of Min., Univ. Wyo., Bull. No. 4.

[4] Knight, W. C., The Rattlesnake, Arago, et al., Oil Fields, Sch. of Min., Univ. Wyo., Bull. No. 4.

Trumbull, L. W., Prospective Oil Fields at Rattlesnake Mountains, State of Wyo. Geologist's Office, Ser. B., Bull. No. 5.

Big Muddy Dome.[1] — West of Glenrock, Wyoming, the Big Muddy Dome is found in the valley of the Platte River. It has dips of from 10 to 38 degrees on the north, but only from 1 to 3 degrees on the southwest. The beds exposed at the crest are the Lower Pierre. The Wall Creek sandstone in the Benton is therefore at a favorable depth, and is well worth testing. It is known to be present, because it outcrops on the flanks of the Casper Mountain to the south. Oil is now being produced from shallower sand.

Muddy Creek. — The oil appearances at Muddy Creek,[2] 16 miles south of Creston, Wyoming, are remarkable for this state in that they are formed by the outcrop of a sand in the Wasatch formation, which is Eocene in age. This would hardly have been expected, since this formation has been thought to be composed of continental deposits. The oil is naturally heavy and has an asphaltum residuum. The only well was located up-dip from the outcrop, and hence there was no possibility of striking this Wasatch sand. The homocline dips to the west without apparent interruption, and hence is not attractive for early development.

Lander.[3]— A long anticline, called by Knight the Shoshone, extending parallel to the Wind River Mountains, has four elongate domes. Upon each of these, wells have been drilled. They are called from north to south the Sage Creek, the Plunkett (Big Popo Agie), and the two associated domes at the south are called the Dallas (Little Popo Agie). It is on the most northern of these domes that most of the work has been done and a pipe line has been built from this to the railroad. The stratigraphy is given in Fig. 126. In each of the domes the Triassic Red Beds (Chugwater) are the oldest formations exposed. It is probable that the oil appearing in the springs in this formation as well as that obtained in the wells is derived from some sandstone member in the Carboniferous limestone (Embar). Little Wind River Dome has very steep dips to the southwest, becoming even vertical in one fault block upon this side. To the northeast they are from 8 to 39 degrees. An oil spring in the alluvium might be the result of a fault, since several faults have been observed near the Little Wind River.

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[1] Barnett, V. H., The Big Muddy Dome, Wyo., U. S. G. S. Bull. 581, pp. 105–117.

[2] Jamison, C. E., The Muddy Creek Oil Field, Wyo., State Geol. Bull. 3B.

[3] Knight, W. C., Petroleum of the Shoshone Anticline, Sch. of Min., Univ. of Wyo., Bull. 2.

Jamison, C. E., Geol. & Min. Res. of Fremont Co., Wyo., State Geol. Bull. 2.

Woodruff, E. G., The Lander Oil Field, U. S. G. S. Bull. 452.

The middle dome (Plunkett field) is near the city of Lander and is crossed by the railroad. The dip is very steep (20 to 70 degrees) on both sides, but steeper to the west. There is a fault with a throw of 500 feet near one of the wells.

The (double) southern dome constituting the Dallas field is also very steep and has faults. Its production has been marketed with difficulty except as fuel for the railroad. The steep dips on each of these domes, which have led to fractures, are a detriment. Much less oil is to be expected than from the unfaulted gentler anticlines in other parts of the state. Naturally the oil is heavier than most of the Wyoming petroleum, being from 22° to 24° B. One well struck oil in the Mancos shale of 42.4° B., but this may be derived from below. (Figs. 123 and 124.)

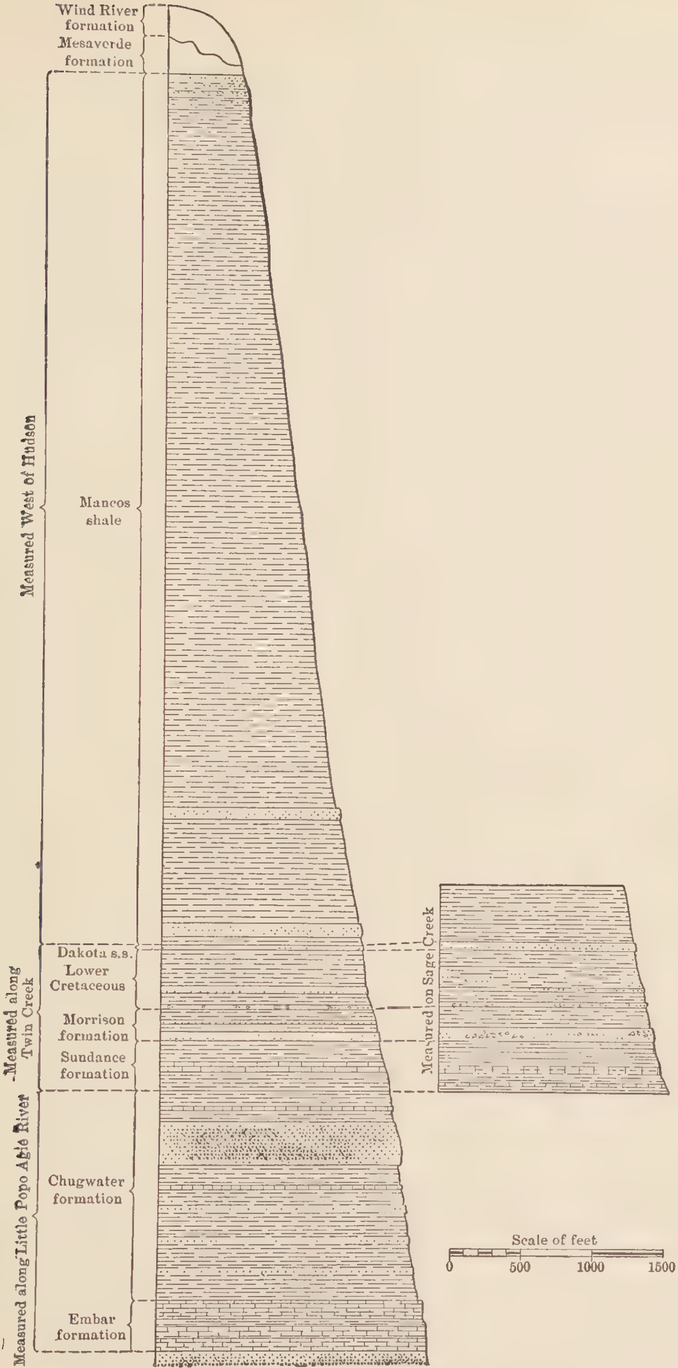
The most interesting feature of the Lander district is the evidence that the formations below the Cretaceous are also oil-bearing. This gives promise to the considerable number of anticlines which have the Triassic, Jurassic or Dakota exposed at their crests.

Labarge and Twin Creek Oil Prospects. — Along the great Absaroka fault are a series of oil springs. The surface beds are usually Tertiary on each side. The oil (from 18° to 20° B.), however, is believed to be derived from the very deep-lying Aspen shale which is productive at Spring Valley and which is correlated with the Mowry shale (productive at Greybull). Prospecting must necessarily be rather blind under the circumstances, and is not likely to lead to a large pool, especially since the Aspen shale is itself thought by Schultz[1] to be 2000 to 4000 feet below the surface of several of these springs.

Spring Valley Field.[2] — Further south the Aspen shale outcrops in a very long north and south line, with a westerly dip of 20° to 40°. Down the dip at convenient depths a number of wells have been drilled along a zone, many miles in length, and this zone will probably be extended in length. The difficulty lies in the nature of the reservoir. It is thought to be made up of many sandy layers of no great lateral extent, for otherwise the oil would have been lost at the outcrop. Sealing could not be expected to be effective here where this bed has been exposed to erosion so long at this steep dip. Naturally with such a reservoir the wells are small and of disappointingly rapid decline.

[1] Schultz, A. R., Geol. of Lincoln County, Wyo., U. S. G. S. Bull. 543.

[2] Veatch, A. C., Geog. and Geol. of Southwestern Wyo., U. S. G. S. Prof. Paper 56.



U. S. Geol. Surv. Bull. 452.

FIG. 126. Columnar section showing the geologic formations in the Lander oil fields.

Rock Formations in Salt Creek Oil Field, Wyoming (C. W. Wegemann)

System.	Series.	Group.	Formations and number recognized in this field.		Character.	Thickness in feet.
Tertiary.	Eocene.		Fort Union formation.		Fine-grained fresh-water sandstone, shale and coal beds.	Several thousand feet.
Tertiary or Cretaceous.	?		Lance formation.		Concretionary buff sandstone and shale-bearing Triceratops remains. Fresh water.	3200
Cretaceous.	Upper Cretaceous.	Montana.	Fox Hills sandstone.		White sandstone and shale. Marine.	700?
			Pierre formation		Shale with several sandstone beds, including that which forms Little Pine Ridge. Marine.	1000
				Parkman sandstone member.	Massive buff sandstone overlain by shale and thin coal beds. Marine and fresh water.	350
					Shale with sandstone stratum 250 feet above its base. Marine.	1100
				Shannon sandstone.	Oil-bearing horizon near base. Marine.	175
					Gray shale. Marine.	1025
		Colorado.	Niobrara shale.		Light-colored shale in parts, somewhat arenaceous. Marine.	735
			Benton shale.		Dark shale, several calcareous beds. Marine.	220
				Wall Creek sandstone.	Buff sandstone, ripple marked, and cross bedded. Petrified wood, marine shells and fish teeth. The principal oil sand of Salt Creek.	80
					Dark shale, several sandstone beds. Marine.	800
				Mowry shale member.	Firm slaty shale, usually forming escarpment. Weathers light gray and bears numerous fish scales. Marine.	300
					Dark shale with one thin, persistent, strongly ripple-marked sandstone.	270
			Dakota(?)sandstone.		Conglomeratic sandstone, oil bearing. Freshwater.	56
Jurassic?			Morrison formation.		Variegated shale with several sandstone beds which in certain localities bear oil. Fresh water.	250

Colorado Foot-hills[1]

The Cretaceous, which has been productive in so many areas in the Rocky Mountain and Great Plains states, is tilted up from under the too thick burden of continental Tertiary, high enough to be reached by the drill along a narrow north and south belt fringing the Front Range in Colorado. Fortunately a few folds "en echelon" widen this zone and assist in the accumulation. On the other hand the great thickness of the Pierre shale, rich in bitumen, is relieved by very few sandstones. This lack is made good by the presence of "crackled" and fissured shale reservoirs. The two commercial fields are in the main each of this type. They differ in the fact that the Boulder pool is on a plunging anticline and the Florence is in part on the flexure forming one limb of a syncline.

Since the reservoirs are in the main of this peculiar nature, and since very little water is found, the principles which would ordinarily be used in locating wells require modification. "Fissuring" is much more abundant at some horizons than others. Fissuring in this sense is to be taken as denoting minute cracks in the main rather than large openings. Evidently flexing and a certain brittleness is necessary for fissuring, since the reservoirs follow beds more than vertical zones. The following rules are suggested for prospecting or "feeling out" in districts such as these:

(1) Follow axes of folds and lines of maximum flexing in monoclines, in the most favorable horizon, rather than the line of maximum flexing at the surface.

(2) Follow the strike.

(3) In "feeling out" from one isolated well, follow a line parallel to another linear series of good wells near-by.

(4) Given two successful wells, follow the line. This is based on the belief that the areas of maximum crackling are oblong.

(5) Wells should be more closely spaced than would be desirable in a sand field, since the reservoir is more erratic.

(6) Wells should not be shot under ordinary circumstances.

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[1] Henderson, J., Foothills Formation of Northern Col., Col. Geol. Surv. 1st Report.

Fenneman, N. M., The Boulder Oil Fields, U. S. G. S. Bull. 213: 383–391.

Fenneman, N. M., Structure of the Boulder Oil Field, U. S. G. S. Bull. 225: 383.

Eldridge, G. H., Florence Oil Field, Trans. A. I. M. E., 20: 16.

Eldridge, G. H., The Florence, Col. Oil Field, U. S. G. S. Bull. 260: 436–40.

Eldridge, G. H., Geology of the Boulder District, Col. U. S. G. S. Bull. 265.

Darton, N. H., Geology and Underground Waters of the Arkansas Valley in eastern Colorado, U. S. G. S. Prof. Paper 52.

Washburne, C. W., Development in the Boulder Oil Field, Colo., U. S. G. S. Bull. 381: 514–16.

Washburne, C. W., The Florence Oil Field, U. S. G. S. Bull. 381: 518–544.

The oil has practically no sulphur or asphalt, and a great deal of paraffin. The gravity at Boulder is 38.6° B., and at Florence 30.7° B. The naphtha yield of the Boulder oil is 16 per cent, and it is 1½ per cent in the Florence oil.

Production of Colorado

	Boulder.	Florence.	Total.	Average price per barrel.
1887	...	...	76,295	$1.000
1888	...	...	297,612	0.900
1889	...	...	316,476	0.885
1890	...	...	368,842	0.84
1891	...	...	665,482	0.84
1892	...	...	824,000	0.84
1893	...	...	594,390	0.838
1894	...	...	515,746	0.589
1895	...	...	438,232	0.767
1896	...	...	361,450	0.883
1897	...	...	384,934	0.86
1898	...	...	444,383	0.829
1899	...	...	390,278	1.035
1900	...	...	317,385	1.019
1901	...	...	460,520	1.000
1902	11,800	385,101	396,901	1.220
1903	36,722	447,203	483,925	0.892
1904	18,167	483,596	501,763	1.152
1905	10,502	365,736	376,238	0.897
1906	48,952	278,630	327,582	0.802
1907	68,353	263,498	331,851	0.822
1908	84,174	295,479	379,653	0.913
1909	85,709	225,062	310,861	1.023
1910	42,186	193,482	239,794	1.015
1911	37,973	187,341	226,926	1.005
1912	15,304	190,498	206,052	0.973
1913	11,796	176,693	188,799	0.926
1914	6,515	215,548	222,773	0.902
1915	...	...	200,000 (est.)	...

The future outlook of the field is not bright. While there is a probability of many good reservoirs, the Pierre dips so quickly to undrillable depths that the area of promising sites is very limited. The greatest efforts have been on the Lyons anticline and success may yet be obtained between the parallels of Loveland and Longmont.

One area that is likely to receive more attention than it has had is Kiowa and its adjoining counties, as the Cretaceous is for the most part more accessible to the drill here, and shows some deformation. Attention should not be limited to either the Pierre shale or Dakota sandstone. The Carlile and Apishapa formations are bituminous in part, and deserve attention, especially the sandstone at the top of the Carlile and sometimes within it.[1]

Pecos

Oil has been obtained in the Pecos valley at Dayton,[2] New Mexico. This valley has long been drilled for artesian water, and it was in such a well that oil was discovered. However, mainly on account of the large proportion of water which this one well produced, and partly on account of the several disappointing dry holes, further search for oil production here is not now active. Since the surface of the valley is covered by wash, obscuring the structure, testing must be mainly based upon the logs of the numerous water wells; or where these are not available prospecting should be restricted to the higher lands, east and west, which are not concealed by alluvium. At Carlsbad, New Mexico, a deep test was remarkable for the extraordinary thickness of gypsum, anhydrite and salt. Similar beds were also encountered in the unsuccessful test at Santa Rosa, far up the valley.

The Permian red and gypsum beds are at the surface and dip eastward from the Guadalupe and Sacramento Mountains. They are underlain by thick strata of limestone and sandstone, the Delaware formation. This is known to show asphalt at the outcrop.[3]

Further to the south, several tests have been drilled on the Toyah flat — some of these, the log of one of which is given by Udden,[4] showed oil but not in commercial quantities. Since this flat is wash-covered, testing may be better guided in the Rustler Hills to the west, where the Rustler dolomite is exposed and where one test was located. While there is no lack of favorable folding with little or no faulting, yet owing to unconformities the convergence renders the folds less significant. The crux of the situation lies in the nature of the Delaware formation. Richardson[5] reports that this consists of limestone and sandstone which show the most extraordinary lateral variation. The scarcity of shale is somewhat disconcerting. Further testing of the whole Pecos field[1] would better await a systematic study of the Delaware formation along its whole outcrop. The part of the valley opposite the most promising section can then be selected in which to seek for promising structure. Otherwise there is danger of much futile drilling, since the scarcity of shale makes the section less promising than would be desired.

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[1] U. S. Geol. Survey, Folios of Walsenburg, El Moro and Apishapa quadrangles.
Darton, N. H., Geology and Underground Waters of the Central Great Plains, U. S. G. S. Prof. Paper 32.
Darton, N. H., Geology and Underground Waters of the Arkansas Valley in Eastern Colorado, U. S. G. S. Prof. Paper 52.

[2] Richardson, G. B., Petroleum near Dayton, New Mexico, U. S. G. S. Bull. 541B.

[3] Richardson, G. B., Geol. of the Trans-Pecos, Texas. Univ. Tex. Min. Surv. Bull. 9.

[4] Udden, J. A., Potash in the Texas Permian. Bull. Univ. Tex. 17, pp. 39–47.

[5] Richardson, G. B., U. S. G. S. Geol. Folio 194, Van Horn Quadrangle.

Rocky Mountain Interior Fields

West of the Front Range of the Rocky Mountains, and included within the great Colorado Plateau, there are a number of localities where surface indications of oil and gas have led to drilling activity. None of these have as yet produced oil in commercially important amounts, hampered as they are by the heavier expense of operating and marketing the product. But changing economic conditions in the future will doubtless lead to the development of profitable production in the course of time and the exploitation of the important oil shale deposits in this region.

The localities to which particular attention has been called by reason of drilling operations or geological reports are described under the following heads:

De Beque Oil Field, Colorado.
Virgin River District in southern Utah.
San Luis Valley, Colorado.
San Juan Oil Field, Utah.
Oil Shales of the Uinta Basin in Colorado and Utah.
Oil and Gas near Green River, Grand County, Utah.
Rangely Oil District, Rio Blanco County, Colorado.

De Beque Oil Field. — This field[2] is located near the town of De Beque, a station on the Denver and Rio Grande Railroad, in Mesa County, Colorado. The formations in the district are Tertiary and Upper Cretaceous.

The carbonaceous Green River formation (Eocene Tertiary) which outcrops on the hills is bituminous in places, and is reported to contain resin, paraffin and fragments of plant tissue. The beds are nearly flat in the northern part of the quadrangle but in the southern part a low anticline occurs, the axis of which has an east-west trend.

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[1] Hill, R. T., Geol. of the Trans-Pecos Province, Texas, and adjacent areas. U. S. G. S. Bulletin in preparation.

[2] Woodruff, E. G., Geology and Petroleum Resources of the De Beque Oil Field, Colorado, U. S. Geol. Survey Bull. 531c.

The first well was drilled in the field in 1902 to a depth of 614 feet; and in the following two years ten more wells were drilled. Most of them obtained small quantities of gas and oil. This did not come from any definite sand horizon, but rather from restricted sandstone lenses in the lower part of the Wasatch (Eocene) or upper part of the Mesaverde formation (Upper Cretaceous). In 1913 a well is reported to have struck a good gas sand under considerable pressure a short distance west of De Beque, at a depth of 1135 feet. A second test in 1914 reports a well of 100 barrels a day, with much water, at a depth of 1900 feet.

No large pool is probable in this locality, as only a small area is structurally favorable. There is porous sandstone in abundance, but there is too little enveloping shale to have favored either the formation of large quantities of oil, or its effective concentration in these beds.

The oil produced is of paraffin grade, with no asphalt, and has an aromatic odor. Different samples showed gravities from 25.6° to 37.75° B.

Petroleum in Southern Utah.[1] — A number of oil seepages in the vicinity of Virgin City, on the Virgin River in Washington County, in the extreme southwestern corner of Utah, led to the drilling of several wells. The first hole was drilled July 13, 1907, to a depth of 610 feet, encountering a "show" of oil at 566 feet. This encouraged prospecting, but later wells failed to obtain oil.

The occurrence of oil in this locality is remarkable in that it is found in red beds of probably Permian age, which overlie the Carboniferous limestone here. Such beds have always been considered unpromising, although asphalt and gas are known in the vicinity of Loco in southern Oklahoma, and the Healdton pool in that state obtains its oil from the base of the Permian red beds.

The Virgin field is considered unpromising for other reasons, principally because of the very restricted and irregular lenses in which the oil is found, the location of which could not be foretold from the surface; and also because structural conditions are unfavorable. It is broken by faults with great displacement.

The oil obtained from this locality is black, consists of saturated hydrocarbons, and averages about 0.45 per cent of sulphur in the form of hydrogen sulphide. It is of fuel oil grade.

San Juan Oil Field, Utah. — This is the most important of the prospective oil fields of the Rocky Mountain interior, so far as appears

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[1] Richardson, G. B., "Petroleum in Southern Utah," U. S. G. S. Bull. 340, p. 343.

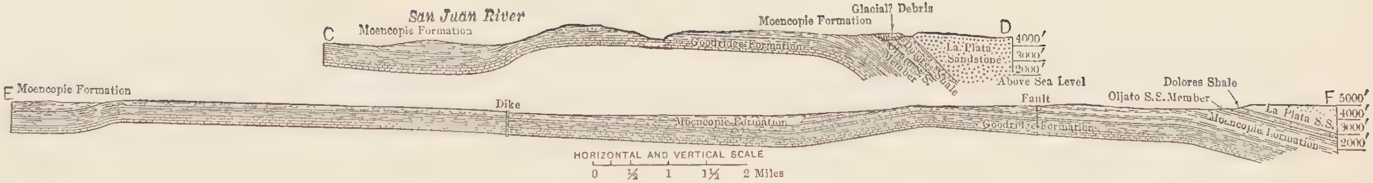

FIG. 127. Section across the San Juan oil field, Utah.

U. S. Geol. Surv. Bull. 471.

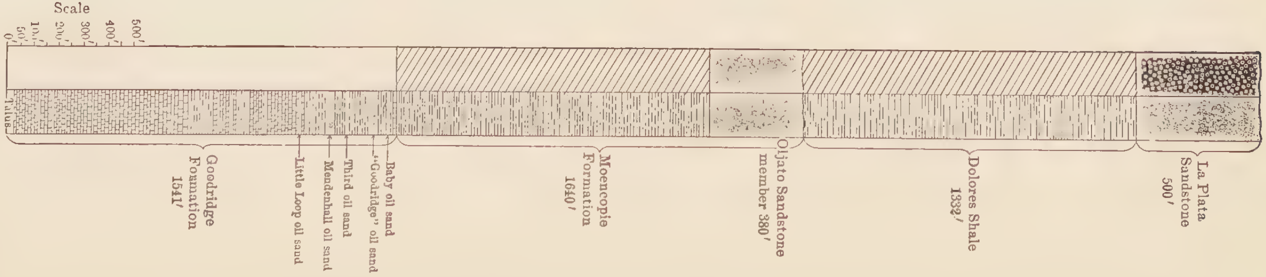

FIG 128. Generalized section showing strata in San Juan oil field.

U. S. Geol. Surv. Bull. 471.

from results up to 1915. Its development has been held back by the expense and difficulty of operating so far from the railroad.

The field is located in a sparsely settled and semi-arid district in southeastern Utah, about 120 miles south of the main line of the Denver and Rio Grande Railroad, and is crossed by the San Juan River.

It is a region of gentle anticlines and synclines (Fig. 127). There have been seepages of oil noticed at a number of places, exuding from the Carboniferous formations along the San Juan Valley. All the productive wells have found oil in the Goodridge formation, generally in sandstone but also in limestone in several wells. At least five oil sands are known (Fig. 128).

The first well was drilled March 4, 1908, to a depth of 225 feet. This gushed oil to a height of 70 feet above the well head. Since then about 30 wells have been drilled, all of which have obtained good shows of oil and a little gas. Woodruff[1] thinks the oil will be widespread, and as there is little water in the formations the oil should be found on the flanks of the broad syncline which comprises a large portion of the field. He does not, however, expect large individual wells. About five wells were productive at the beginning of 1914.

The oil produced contains paraffin with a small amount of asphalt, and its gravity is about 38° B. The following analysis is reported by the U. S. Geological Survey:

CHEMICAL AND PHYSICAL PROPERTIES OF OIL IN THE SAN JUAN OIL FIELD, UTAH

Distillation by Engler's method.								Sulphur (per cent).	Paraffin (per cent).	Asphalt (per cent).	Unsaturated hydrocarbons (per cent).	
Begins to boil (° C.)	By volume.											
	To 150° C.		150°-300° C.		Residuum.		Total cubic centimeters.					
	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.	Cubic centimeters.	Specific gravity.					Crude.	100°-300° C.
70	12.0	0.7245	36.0	0.7941	49.3	0.8974	99.3	0.26	6.09	0.80	20.4	1.0
78	11.0	0.7235	35.0	0.7976	51.0	0.8946	97.0	0.18	5.29	0.60	14.8	6.0
73	12.0	0.7130	36.0	0.7941	49.5	0.8975	97.5	0.20	3.25	1.11	14.4	8.0
97	10.0	0.7395	37.0	0.8021	52.0	0.8986	99.0	0.40	6.79	0.49	19.2	6.0

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[1] Woodruff, E. G., Geology of the San Juan Oil Field, Utah, U. S. G. S. Bull. 471.

Concerning the character of the oil, Mr. David T. Day remarks:

> These oils, as shown by the analyses, are unusually light in specific gravity. They yield more than the average amount of gasoline and of burning oil. The light specific gravity of the burning oil fraction compared to the average, the considerable amount of paraffin wax, and the comparatively low proportion of unsaturated hydrocarbons show that these oils are somewhat similar to the oil from Lima, Ohio, with a smaller proportion of sulphur. In fact, the amount of sulphur is less than in many oils in Illinois, which are refined without special apparatus for eliminating sulphur. Taken altogether, these oils are well suited for the manufacture of gasoline and kerosene, and there is every indication that the residuum would yield valuable lubricating oils.

Conditions point to the likelihood of this field being but slightly developed until transportation facilities are more adequate, and until the more prolific Wyoming fields show signs of exhaustion or inability to fill the growing market.

Other oil springs are reported with similar stratigraphic conditions as far north as Moab, Utah. These will be prospected as the economic situation in this region warrants. The development of some of these localities may wait until the price of oil has risen high enough to warrant the working of the oil-bearing shale beds of the Rocky Mountain interior, which will lead to the building of more refineries in these states.

San Luis Valley, Colorado. — C. E. Seibenthal[1] reports gas in wells from the Alamosa formation (Quaternary), accompanying a peculiarly colored artesian water. This gas area lies between the towns of Alamosa and Moffat in south central Colorado.

Oil Shales of the Uinta Basin[2] *in Colorado and Utah.* — As the most promising oil fields of North America are being rapidly developed, and less favorable areas begin to receive attention, the resulting rise in the market for crude oil will turn the attention of refiners to the shale oil deposits of Colorado and Utah. Of these, probably the richest and most accessible and extensive are in the Green River formation in Garfield County, Colorado, and in Uinta and Wasatch Counties in Utah.

Samples have been taken by geologists of the U. S. Geological Survey at points along an extensive outcrop in the above counties, which yielded upon analysis from 10 to 68 gallons of oil per ton. The oil shale occurs in lenses of irregular thickness and extent from a fraction of an inch to 80 feet or more and it is known to underlie very considerable areas. None of these lands had been withdrawn from entry by the Department of the Interior up to 1915.

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[1] Seibenthal, C. E., Geology and Water Resources of the San Luis Valley, Colorado, U. S. G. S. Water Supply Paper 240.

[2] U. S. Geological Survey, Mineral Resources, 1913.

Woodruff, E. G. and Day, D. T., Oil Shales of Northwestern Colorado and Northeastern Utah, U. S. G. S. Bull. 581A.

As is well known, such shales have been profitably worked for many years in Scotland where in 1904 the production of shale amounted to 2,709,840 tons with a content of 63,000,000 gallons of crude oil. This yielded marketable products of 2,517,296 gallons of naphtha, 16,991,748 gallons of burning oil, 37,997 tons of gas oil, 39,487 tons of lubricating oil, 22,476 tons of paraffin wax, and 49,600 tons of ammonia salts. In 1913 the production of oil shale in Scotland was 3,150,000 tons, from which about 65,000,000 gallons of oil was obtained. This yield of 20 gallons of oil to the ton of shale may be contrasted with the assumed average yield of 40 gallons from the Colorado and Utah shales. The cost of mining and treating the shale in Scotland for both oil and by-products is said to be about $1.85 a ton. Large areas of the Colorado and Utah shales are more easily accessible to mining than is the Scottish shale being mined at the present time.

Oil and Gas near Green River, Grand County, Utah. — There are occurrences of bituminous and asphalt-bearing sandstone in this field, which have led to its being prospected for the past twenty years. Practically all drilling has been done along and adjacent to a fault zone which crosses the field in a northwest by southeast direction. Gas is found in the Mancos shale in small quantities. The Dakota sand is within reach of the drill, but as a rule contains fresh water, or water containing sulphides, sometimes with a little gas. The drill has developed both gas and oil shows in sandstone lenses in the gray and red shales of the St. Elmo formation below the Dakota. These beds are probably of Jurassic age. None of these shows have been of commercial importance.

The field includes Townships 21, 22, 23, 24, South; Ranges 16, 17, 18, 19, 20, East of the Salt Lake Meridian. Several small domes are reported to warrant testing when further drilling is undertaken.

Rangely Oil District,[1] *Rio Blanco County, Colorado.* — This district is located in Raven Park in the extreme northwestern part of Rio Blanco County. Several wells have been drilled which pumped or bailed a little oil, but no commercial production has been developed.

This district is underlain by the Dakota sand, but in most places this horizon lies at a depth greater than 3500 feet, which at the present time is too deep to warrant drilling for oil or gas. The overlying Mancos shales are approximately 5000 feet thick, but they are eroded to some extent from the tops of the anticlines. One well drilled to a depth of about 3700 feet through the Mancos shales failed to reach the Dakota. There is no evidence of oil or gas at the outcrop of the Dakota in the northern part of the field, and it is quite uniformly porous and of uniform thickness. It may, therefore, be expected to contain water throughout most of the field. However, the extensive dome which crosses the field may have retained some oil, and quite probably some gas at its crest.

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[1] Gale, H. S., Geology of the Rangely Oil District, Rio Blanco Co., Colorado, U. S. Geol. Survey Bull. 350.

There is an oil pay encountered in the Mancos shales in sandy lenses. If porous lenses could be found of sufficient extent in these shales, it is probable that a good production would result. There is, however, no way of locating such lenses from the surface; and the outcrop of these beds does not offer much evidence of their frequency. It must be expected, therefore, that wells will probably be of relatively small production, and the percentage of dry holes high.

The oil is a clear light red with a decided green fluorescence. It is a paraffin oil of about 44° B. containing no sulphur or asphalt. Analysis shows the following content of light oils:

	Gravity, ° B.	Per cent.
Gasoline and naphtha below 150° C.	0.68	25
Illuminating oil, 150–300° C.	0.751	45
Residue above 300° C.		27
Loss		3

Snake River Field

The Snake River field[1] has been described by Washburne as located in southeastern Oregon and western Idaho, near the towns of Vale, Ontario and Nyssa, in Malheur County in Oregon, and near Payette and Weiser in Idaho. The region described extends along the Snake River in a north-south direction for about 30 miles, and its western limit lies about 25 miles west of the river.

Numerous traces of oil are reported in this district, which is characterized by gas mounds and springs, and so-called mud volcanoes which are sometimes accompanied by hot springs.[2] Prospecting started about 1904, and more than 15 wells were drilled in Malheur County, besides many more shallow water wells throughout the district. These varied in depth from shallow water wells to a 3650-foot hole drilled at Ontario, Oregon. Several wells struck small shows of oil of no commercial importance, but at the same time several good flows of gas under high pressure were developed.

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[1] U. S. G. S. Bull. 431.

[2] Bell, R. N., Ninth Ann. Rept. Min. Industry of Idaho, 1907, p. 86.

The geologic section consists of 4200 feet or more of sediments of fresh water origin, lying in general horizontally above igneous rocks. Gas is found at various horizons throughout the region, in sand and conglomerate strata of Tertiary age. Fossils are relatively scarce in these beds, a condition which Washburne does not think promising for the development of commercial oil production, although he is more hopeful for gas. And for this there is more evidence.

Some small faults apparently exist, but are not well marked or of much importance. The structure of the region is not pronounced, although some low folds have been noted. The Snake River valley near Fayette is a low broad syncline. Smaller structures are located with difficulty, on account of the softness of the beds and the alluvial covering, but as there is apparently considerable unconformity between the lower beds, such sedimentary gradients may be more important in a part of the area than the gradient occasioned by minor folding.

A sample of oil collected by Washburne in 1909 was of a very light color and low viscosity, and he concluded it was of paraffin grade. Samples collected were too small to determine their gravity. Washburne considers the evidence strong for the inorganic theory of the origin of the gas and oil.

Alaska

There are four localities on the Pacific coast of Alaska[1] where petroleum seepages are known, and Leffingwell, quoted by Brooks, reports

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[1] Martin, G. C., The Petroleum Fields of the Pacific Coast of Alaska, with an account of the Bering River Coal Deposits, U. S. Geol. Surv. Bull. 250, pp. 9–27, 1905.

Martin, G. C., Geology and Mineral Resources of the Controller Bay Region, Alaska, U. S. Geol. Surv. Bull. 335, pp. 112–130, 1908.

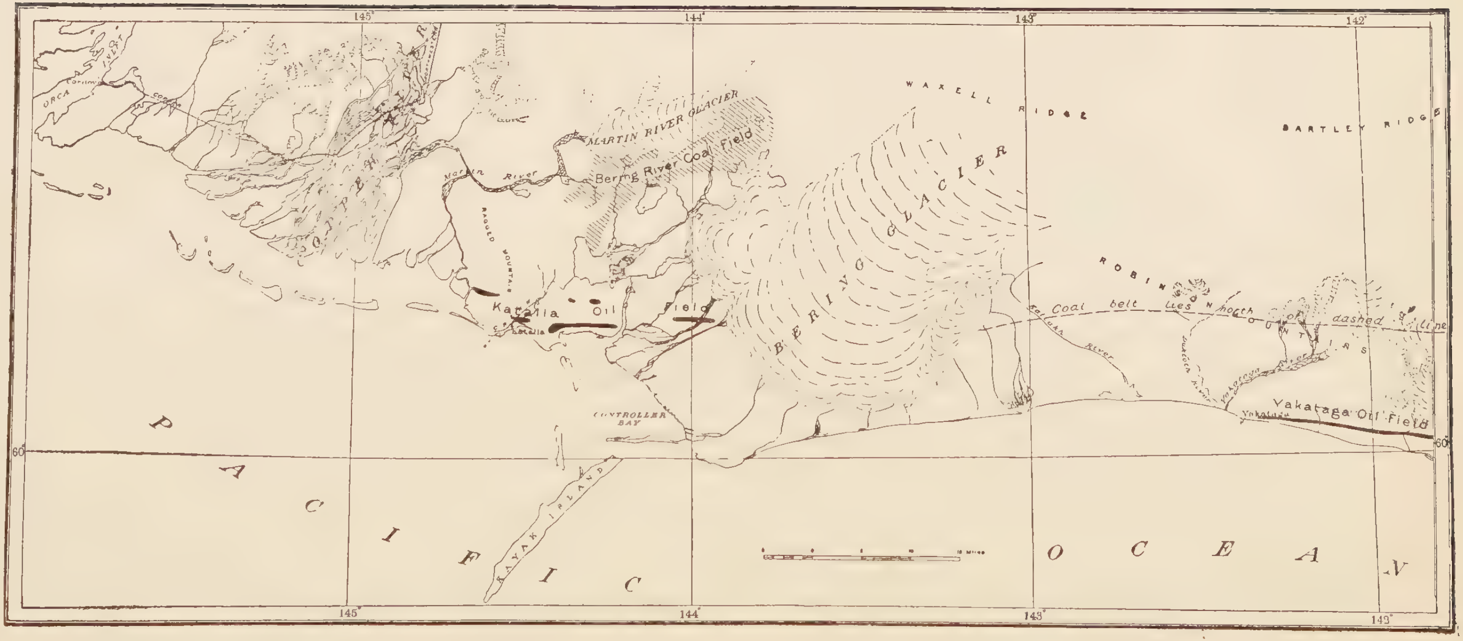
Martin, G. C., and Katz, F. J., A Geologic Reconnaissance of the Iliamna Region, Alaska, U. S. Geol. Surv. Bull. 485, pp. 126–130, 1912.

Maddern, A. G., Mineral Deposits of the Yakataga District, U. S. Geol. Surv. Bull. 592, pp. 143–147, 1914.

Brooks, Mineral Resources in Alaska in 1908, U. S. Geol. Surv. Bull. 379, pp. 61–62, 1909.

Brooks, A. H., The Petroleum Fields of Alaska, Bull. A. I. M. E., Feb., 1915, pp. 199–207.

Brooks, A. H., Mineral Resources of Alaska, U. S. Geol. Surv. Bull. 592.



Brooks, Trans. A. I. M. E., 1914.

FIG. 129. Map showing location of Katalla and Yakataga oil fields, Alaska.

the occurrence of a considerable deposit of asphaltic residue at Smith's Bay on the Arctic Ocean, 100 miles east of Point Barrow.

The four Pacific Coast occurrences are located at Yakataga, Katalla on Controller Bay, Fig. 129, Iniskin Bay on Cook Inlet, and Cold Bay on the Alaska Peninsula (Fig. 130). There has been no commercial production from any of these fields except Katalla, although wells have been drilled at the last three points. At Katalla several fairly good wells have been drilled, to a depth of about 1000 feet, which produce from two to ten barrels per day. This is refined locally for its gasoline content.

The surface formations of the Katalla field are shales, sandstones and conglomerates of Tertiary age, sharply folded and faulted, with some small basalt or diabase dikes and sills. The oil occurs in a fissured shale. The general strike is about North 20° East, and the line of seepages follows the same direction.

The surface formations of the Yakataga field are sand and shales of Tertiary age, and the seepages seem to follow the strike of a strongly marked anticline running east and west. No drilling had been done in the region up to 1915, and it is almost inaccessible. The structure is simpler than that of Katalla.

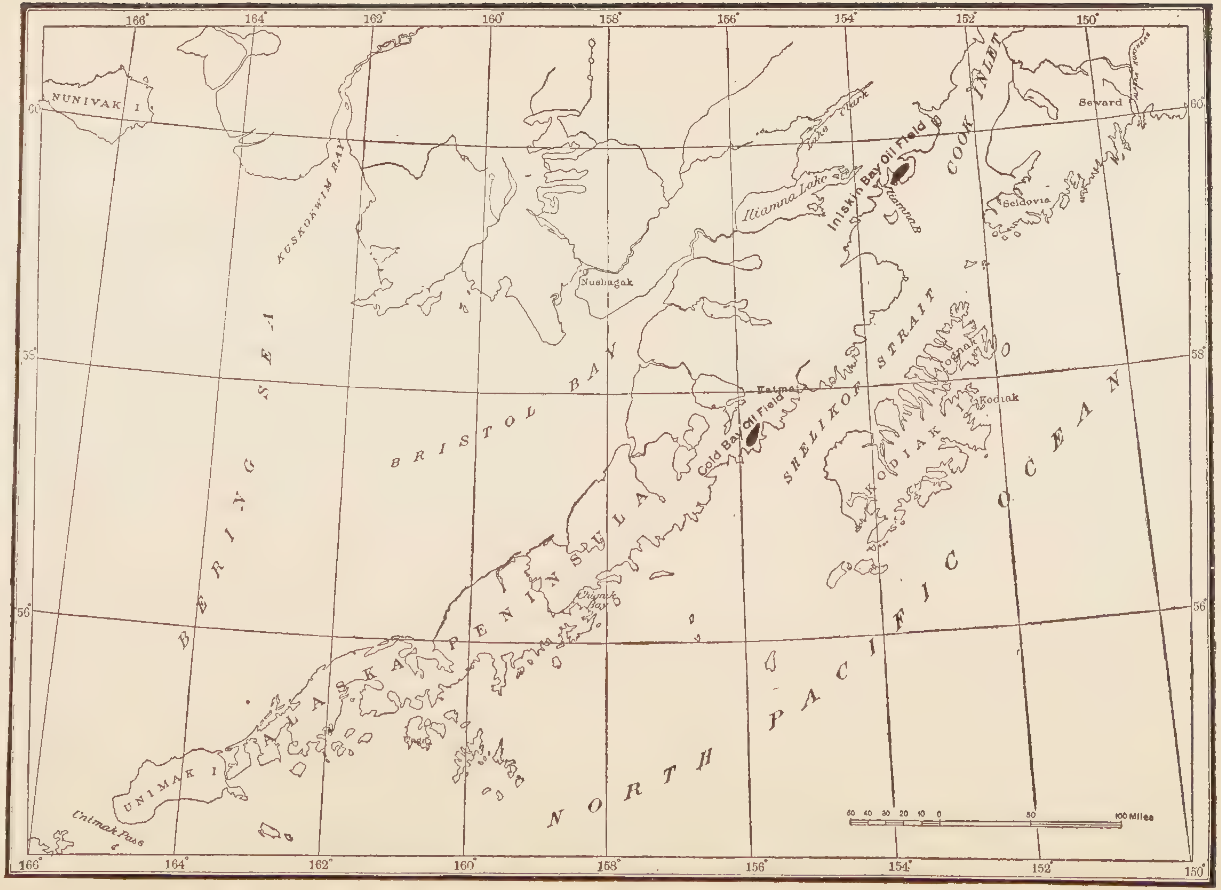
The formations in the Iniskin Bay and Cold Bay fields are of Middle Jurassic age, and the seepages occur on broad open folds and are sometimes accompanied by gas. Some faulting has been observed.

The Smith Bay locality mentioned above is not readily accessible, and at the present time cannot be considered a prospect of commercial importance. Of the Pacific Coast fields, all are readily accessible except Yakataga, and this might be made so by developing an overland route from Katalla.

The following is the average analysis of a number of samples taken from wells drilled in the Katalla field, as reported by various authorities:

Color.	Specific gravity.	Flash pt., deg. F.	Benzene.	Kerosene.	Lubricants.	Residue coke and loss.
			Per cent.	Per cent.	Per cent.	Per cent.
Light green to dark red...............	0.8216 (40° Baumé)	70	31.4	32.7	37.8	6.35

So far as known, the oils from all the Alaskan fields are of a refining grade, with a paraffin base, and contain little sulphur, being similar to Pennsylvania oils.



Brooks, *Trans. A. I. M. E.*, 1914.

FIG. 130. Map showing location of Iniskin Bay and Cold Bay oil field, Alaska.

Coast Range Field

The Coast Range field as distinguished by the authors includes a narrow strip extending along the Pacific Coast from Cape Blanco in Oregon, northward through Oregon and Washington and including the southern part of Vancouver Island.

No oil or gas in commercial quantities has been produced in this area up to the present time. Several unsuccessful wells have been drilled in Tillamook, Multonomah and Clackamas Counties in northwestern Oregon.[1] The northern part of the Olympic Peninsula[2] and the vicinity of Tacoma and Seattle have been the scene of considerable drilling activity during 1913 and 1914, without, however, resulting in the discovery of more than small shows of oil and gas.

The formations in this Coast Range belt are shales, clay and sands of Tertiary age (Eocene, Miocene and Oligocene) of great thickness. North of the Hoh River on the Olympic Peninsula, the Hoh formation outcrops. This is doubtfully referred to the Cretaceous or possibly the Jurassic.[3] Weaver[4] states that the Tertiary formations of western Lewis, Cowlitz, Pacific and southern Chehalis Counties in Washington are in part of marine origin and contain considerable quantities of marine fossils. They are composed of a favorable alternation of shales and sandstones and have been folded into shallow folds. He states that no seepages or direct indications of the presence of petroleum are known to occur in these beds. The only definite indications of the presence of petroleum in the state of Washington are those described by Lupton as occurring on the Olympic Peninsula in the Hoh formation. These consist of oil-saturated sands and mud and gas vents or "springs." A number of wells have been drilled near the principal "springs," and three more were drilling in 1915; but up to that time only slight shows of gas or oil had been encountered.

Drilling has also been carried on during 1914 and 1915 in Thurston County in the vicinity of Tenino, in the Tertiary formations.

In northwestern Oregon the Tertiary formations lie in a broad geanticline broken by many igneous intrusions. Washburne states that in general this district has geological characteristics similar to the Mexican oil fields as regards the age and the character of the upper formations, the relatively low dips (only exceptionally as high as 15 degrees) and the prevalence of basalt intrusions and sandstone dikes. However, unlike the Mexican fields, such lines of weakness as dikes, faults and intrusions in Oregon are not accompanied by oil seepages. Washburne mentions several localities where the rocks still hold small amounts of liquid oil, although no true seepages are known:

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[1] Washburne, C. W., U. S. G. S. Bull. 590.

[2] Lupton, C. T., U. S. G. S. Bull. 581B.

[3] Arnold, R., Geol. Recon. of the Coast of the Olympic Peninsula Washington, Geol. Soc. of America, Vol. 17, pp. 461–2; and Arnold and Hannibal, Am. Philos. Soc. Proc., Vol. 52, No. 212, pp. 564–73.

[4] Weaver, C. E., The Possible Occurrence of Oil and Gas Fields in Washington, Bull. A. I. M. E. July 1915.

1. In porous basalt on the Johnson ranch, on the north fork of Siuslaw River, western Lane County.
2. In concretions of limestone in shale, at Hawkins ranch, on Bear River, Washington.
3. In similar concretions at Cementville, on the north fork of the Columbia River, opposite Astoria.
4. In concretions from several localities in Astoria.

Oil residues are much more common, and are usually found as black veinlets of solid hydrocarbons in many different kinds of rock, as at Coos Bay.

He recommends the drilling of a well on the Westport arch in order to determine whether the formations are oil-bearing, and states, "It is true that many good oil fields have been developed where no surface indications exist, but so far as known such fields are not cut by many vertical dikes. In a fractured region like northwestern Oregon it therefore seems reasonable to believe that the general absence of true seeps is an argument against the presence of much oil underground."

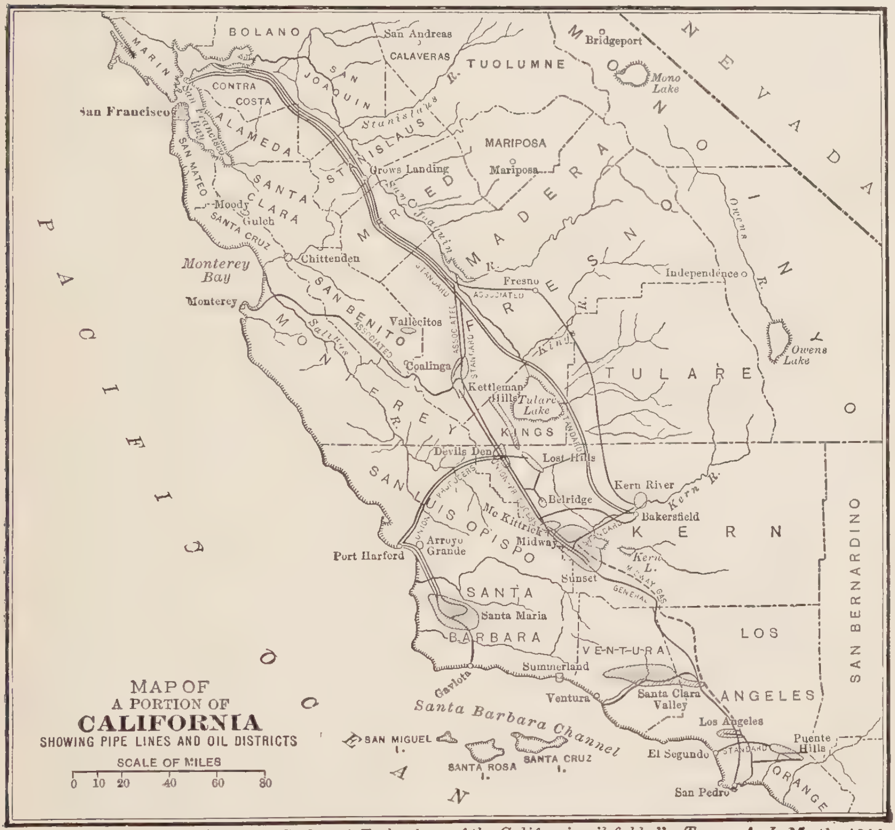
The small quantities of petroleum found along the Coast Range belt are of good quality paraffin oil. Several of the wells being drilled on the Olympic Peninsula and near Tacoma in 1915 are located on good anticlines, and will constitute a fair test of the oil-bearing nature of the formations, both Tertiary and Cretaceous. In case the recommendation to test the Westport arch near Coos Bay in Oregon is followed, it may be considered a test in some degree also of the Tertiary beds of this region, and with the Washington wells should give important evidence as to the oil and gas possibilities of these fields.

California Fields

Limits. — The oil pools of California are all located in the southern half of the state, from Fresno County to the Mexican border (Fig. 131). Oil indications are encountered along the Coast Range as far north as

San Francisco, but there are few prospects of economic importance far from the present producing fields.

The fields of southern California are divided both geologically and topographically into the *San Joaquin Valley* districts, and the *Coast* districts. Arnold[1] estimates that the proved territory contains approximately 100,000 acres, the prospective area 25,600 acres.



Arnold and Garfias, "Geol. and Technology of the California oil fields." Trans. A. I. M. E., 1914.

FIG. 131. Map of a portion of California showing pipe lines and oil districts.

The San Joaquin valley districts comprise the Coalinga, Lost Hills, McKittrick, Midway, Sunset and Kern River pools. In 1914 these pools produced 78,121,976 barrels of oil, or nearly 80 per cent of the total production of the State.

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[1] Arnold, Ralph, Petroleum Resources of the U. S. Econ. Geology, Vol. 10, pp. 675–712.

The Coast districts comprise the Santa Maria, Summerland, Santa Clara Valley, Los Angeles and Puente Hills pools. These produced the remainder of the State's production. The oil from these pools is largely used for refining and is of lighter gravity than that from the San Joaquin valley pools, which is principally used for fuel.

Marketed Production and Value of Petroleum in California in 1914, by Districts and Counties, in Barrels[1]

District and county.	1914.		
	Quantity.	Value.	Price per barrel.
Coastal and southern:			
Los Angeles County			
Los Angeles city	296,862	$153,879	$0.518
Newhall	127,706	97,999	0.767
Salt Lake-Sherman	2,058,820	1,054,189	0.512
Puente Whittier	667,504	383,611	0.575
Orange County			
Fullerton[2]	13,260,226	8,202,968	0.618
Ventura County			
Santa Paula	857,685	947,681	1.104
Santa Barbara County			
Lompoc Santa Maria	4,310,236	2,163,912	0.502
Summerland	53,561	32,692	0.610
Monterey County San Mateo County San Luis Obispo County Santa Clara County	20,751	10,637	0.512
San Joaquin Valley:			
Fresno County			
Coalinga	15,692,733	7,173,559	0.457
Kern County			
Lost Hills	3,325,516	1,961,995	0.589
Kern River	6,683,592	2,589,238	0.387
McKittrick[3]	5,315,638	2,054,342	0.386
Midway	37,862,683	17,363,080	0.458
Sunset	9,241,814	3,876,314	0.419
Total	62,429,243	27,844,969	0.446
Grand total	99,775,327	$48,066,096	$0.481

[1] These statistics as well as most of the others are from Mineral Resources, for 1914, U. S. G. S.

[2] Includes Coyote Hills.

[3] Includes Belridge.

These pools are all described in detail by Arnold and Garfias[1] in their admirable paper entitled, "Geology and Technology of the California Oil Fields." Drilling operations and history are taken up at still

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[1] Bull. A. I. M. E., Mar. 1914.

GEOLOGIC FORMATIONS

Tentative correlation of oil-bearing formations of southern California with the standard geologic section.

Period.	System.	Series.	Southern California section.	Estimated thickness, feet.
Cenozoic	Quaternary	Recent Pleistocene	Alluvium, San Pedro, Fernando (in part)	1,000
			Unconformity	
	Tertiary	Pliocene	Deadman Island, Fernando (in part)	1,000
			Unconformity	
		Upper Miocene	Etchegoin, Fernando (in part), Jacalitos (in part), McKittrick (in part)	7,000
			Unconformity	
			Santa Margarita, Jacalitos (in part), McKittrick (in part)	2,000
			Unconformity	
		Lower Miocene	Monterey (Puente, Modelo)	7,000
			Unconformity	
			Vaqueros (Puente in part)	3,000
			Unconformity	
		Oligocene	Sespe	4,300
			Unconformity	
		Eocene	Tejon (Topa Topa)	5,000
			Unconformity	
			Martinez	4,000
			Unconformity	
Mesozoic	Cretaceous	Upper Cretaceous	Chico	6,000
			Unconformity	
		Lower Cretaceous	Knoxville	7,000
			Unconformity	
	Jurassic?		Franciscan	12,000
			Unconformity	
Paleozoic		?	Granite	?
			Unconformity	
			Black schist, limestone	?
			Total	59,300

greater length by R. P. McLaughlin[1] in "The Petroleum Industry of California," while the detailed geology as worked out by the geologists of the U. S. Geological Survey is given in their various bulletins.

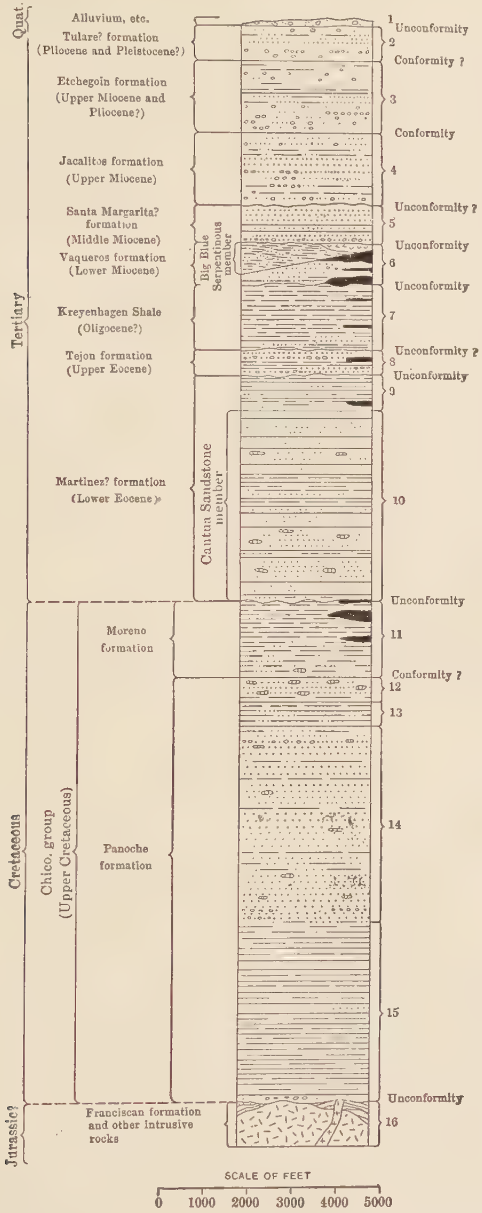
The exploitation of oil in California commenced in the early sixties, attention having been first called to the presence of petroleum by the discovery of numerous seepages or break deposits. Most of the early drilling was done in Ventura County, while the Los Angeles city field was developed during 1892. These were shallow wells about 800 feet in depth. Since that time development has been steady until the state is producing approximately 250,000 barrels per day (1915).

Oil is produced from beds at intervals from the Upper Cretaceous (Knoxville-Chico beds) to the Quaternary in these fields, but most of the important commercial production from this state occurs in or has apparently arisen from the Miocene Tertiary (Fig. 132). The sand-bodies from which the oil is produced are very numerous and often lenticular. The study of oil occurrences in these fields has added greatly to our knowledge of its origin and the laws of accumulation. Arnold, Anderson and Pack have offered almost conclusive proof of the relation of the origin of the oil in California to extensive beds of diatomaceous shales. Many of the oil sands are soft and unconsolidated, and in the Santa Maria field a portion of the oil is reported to be produced from fractured and jointed shale. The soft sands encountered in some wells with high pressure lead to the expulsion of large quantities of sand with the oil and gas. This may eventually "sand-up" the hole, or may produce a large collecting reservoir favorable for further production.

Oil is produced from practically every known type of geological structure in the California fields, complicated by varying water conditions, outcrops, faults and igneous intrusions. In no other great field except in Russia are large pools found in connection with dips as steep as those in California.

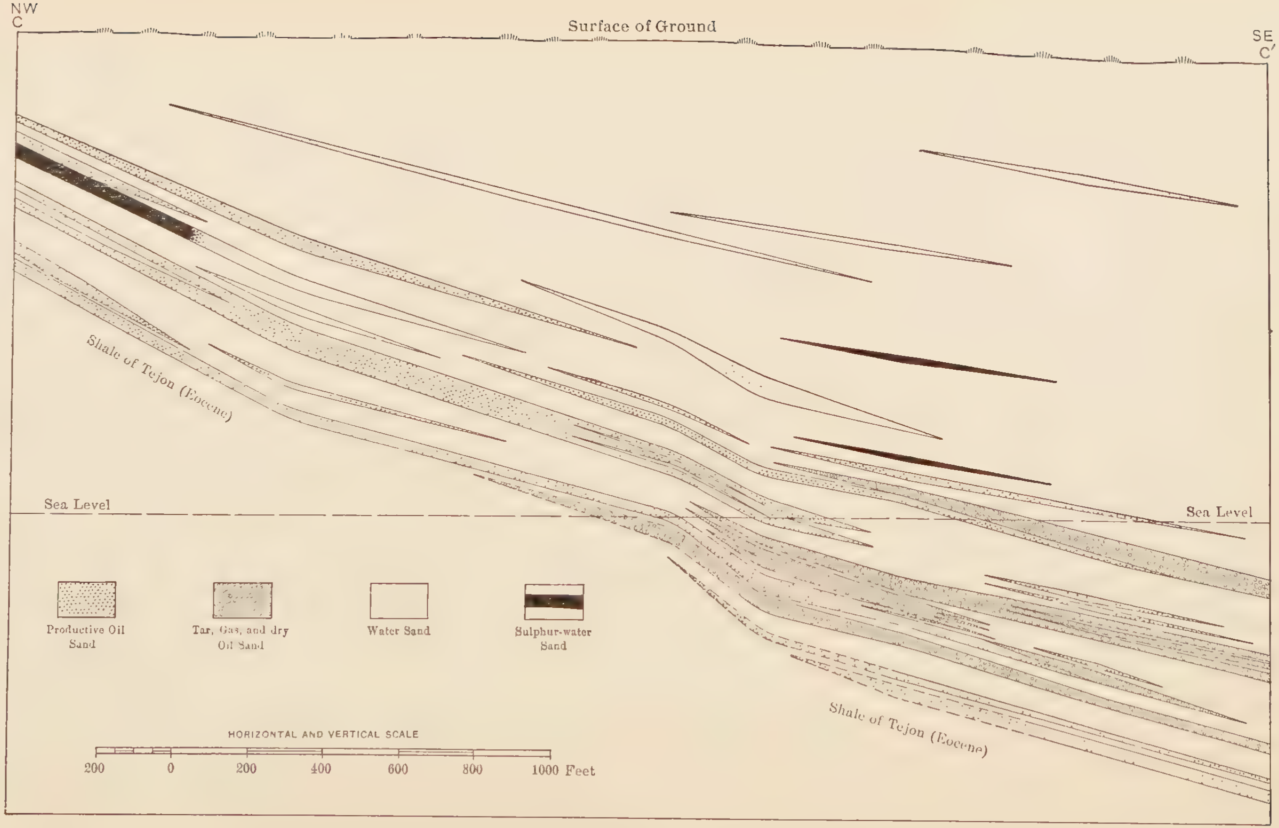
The consensus of opinion among geologists seems to be that no large pools will be developed in California outside of the present proved or withdrawn areas. These areas will be extended by continued deeper drilling and by "feeling out," while there remain a great many as yet undrilled or only partly drilled leases. The sands are unusually numerous (Fig. 133) and prolific, the yield per well is high, and the decline curves are more favorable than for any field in North America except Mexico. Various esti-

[1] California State Mining Bureau, Bull. 69.



From Anderson and Pack.

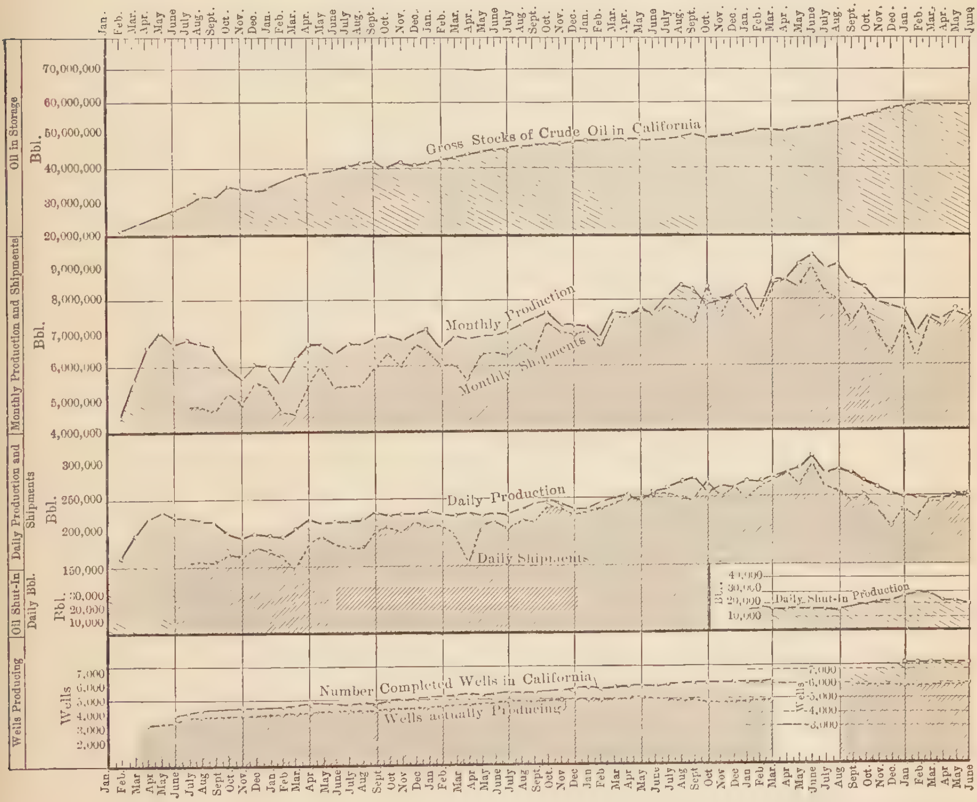
FIG. 132. Generalized columnar section of the rocks in the Diablo Range in the southern part of the region between Coalinga and Livermore Pass.



Arnold, U. S. Geol. Surv. Bull. 398.

FIG. 133. Hypothetical section through a part of the Coalinga field.

mates have been made as to the total amount of oil available, which varies, with the weight given by each authority to various estimated factors, from 8,000,000,000 to 17,000,000,000 barrels. This will vary so much with economic factors which cannot be predicted that all such attempts must be taken with a wide margin of allowance. Arnold predicts that the annual production for California will not greatly exceed 100,000,000 barrels, and that the production curve must soon decline.



J. H. Wolf, Western Engineering, Oct., 1915.

FIG. 134.

Most of the California petroleum is asphaltic. One of the exceptions is the paraffin oil produced from the Upper Cretaceous formations in the Coalinga district. About 40 per cent is commonly known as heavy or fuel oil, while about 60 per cent is passed through stills for topping or refining, the residuum being used for fuel. The bulk of the production is, therefore, used for fuel or road-dressing, either in its crude state or as residuum. Most of it is used in the Pacific States and Canada, as fuel on the railroads or for marine purposes, although some is exported to adjacent states to the East and to Hawaii, Japan, Alaska, Panama and South America. With the increasing consumption, the time is rapidly approaching when an increased price will result in the application of the new high-pressure cracking processes to the transformation of larger percentages of these heavy oils to light products. The crude oil will also be used to a greater extent in internal combustion engines of the Diesel and De LaVergne types. Meanwhile the oil from the prolific Mexican fields will be produced in greater quantities, and will thus prevent any great rise in price, in the immediate future, for fuel oil. The California fields have been much more fully described than the other American fields, as the accompanying bibliography shows, and the excellent summaries by Arnold and Garfias, and McLaughlin make a fuller treatment here unnecessary.

Watts, W. L., Gas and Petroleum Yielding Formations of the Central Valley of California, 1894. Cal. State Min. Bureau Bull. 3.

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Eldridge, G. H., The asphalt and bituminous rock deposits of the United States. U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 209–452, 1901.

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Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal. U. S. Geol. Survey Bull. 322, 1907.

Arnold, Ralph, The Miner ranch oil field, Contra Costa County, Cal. U. S. Geol. Survey Bull. 340, pp. 339–342, 1908.

Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga oil district, Fresno and Kings Counties, Cal. U. S. Geol. Survey Bull. 357, 1908.

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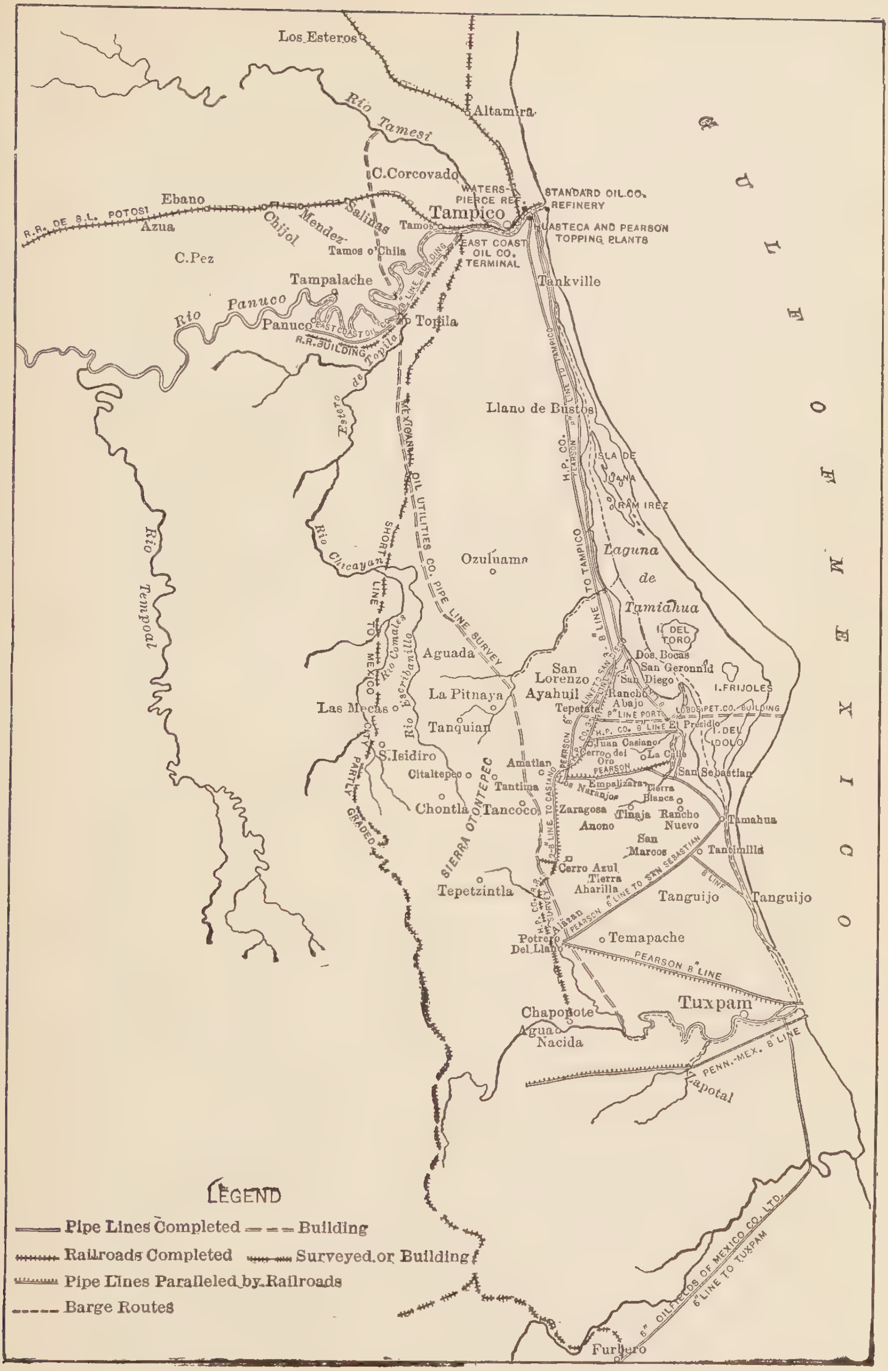

FIG. 135. Sketch map of the Mexican oil fields, showing pipe lines and railroads.

Arnold, Ralph, and Johnson, H. R., Preliminary report on the McKittrick-Sunset oil region, Kern and San Luis Obispo Counties, Cal. U. S. Geol. Survey Bull. 406, 1910.

Anderson, Robert, Preliminary report on the geology and oil prospects of the Cantua-Panoche region, California. U. S. Geol. Survey Bull. 431, pp. 59–87, 1911.

Anderson, Robert, Preliminary report on the geology and possible oil resources of the south end of the San Joaquin Valley, Cal. U. S. Geol. Survey Bull. 471, pp. 106–136, 1912.

Pack, R. W., Reconnaissance of the Barstow-Kramer region, Cal. U. S. Geol. Survey Bull. 541, pp. 141–154, 1914.

Pack, R. W., and English, W. A., Geology and oil prospects of Waltham, Priest, Bitterwater, and Peachtree valleys, central California. U. S. Geol. Survey Bull. 581, pp. 119–160, 1915.

Anderson, Robt., and Pack, R. W., Geology and Oil Resource of the San Joaquin Valley North of Coalinga, California. U. S. Geol. Survey Bull. 603.

Prutzman, P. W., Petroleum in Southern California, 1913. Cal. State Min. Bureau Bull. 63, 419 pp.

Arnold, Ralph, and Garfias, V. R., The Cementing Process of Excluding Water from Oil Wells as Practiced in California, 1913. U. S. Bureau of Mines Tech. Paper 32.

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Vera Cruz-Tamaulipas Field

The most important oil fields in Mexico (Fig. 135) are those in the southern part of the State of Tamaulipas and the northern half of the State of Vera Cruz, extending in a strip about fifty miles wide between the Gulf Coast and the foot-hills in the states of Hidalgo and San Luis Potosi. Not all of this area has been prospected, but groups of wells of large productivity have been drilled at about twenty different localities.

The first production of importance in Mexico was during the year of 1904, and amounted to about 200,000 barrels for the year. In 1914 the production was approximately 26,000,000 barrels, or an average of about 72,000 barrels per day. During the summer of 1915 the field was producing about 97,000 barrels per day, though the wells already drilled are thought to have a potential production of about 500,000 barrels per day. The production for the year 1915 is estimated to have been only 22,000,000 barrels, so greatly has the production been restricted. This curtailment was due to governmental interference, to market conditions and to transportation difficulties brought about by over-production in the United States, and to a lesser extent by the European war.

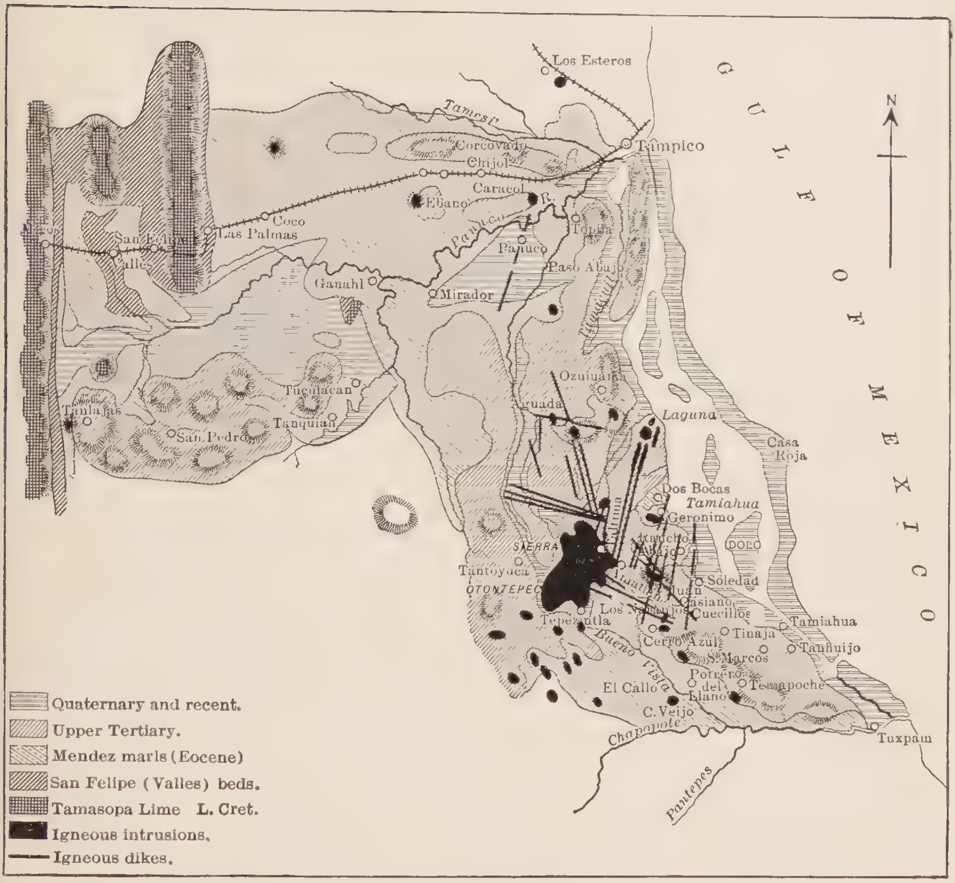

FIG. 136. Generalized map of Mexican oil fields showing areal geology, location of main basaltic intrusions, and strike of main dikes in the central district.

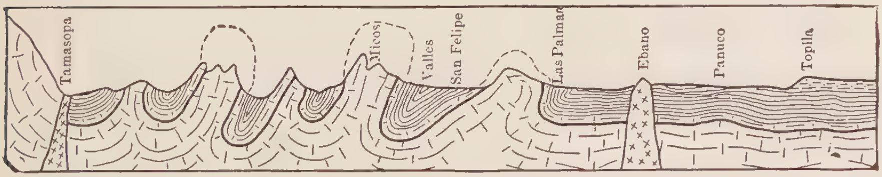

FIG. 137. Generalized section east and west through northern part of the oil fields. After Jeffreys.

Among the most important producing areas in this field are those of Ebano, Panuco, Topila, Juan Casiano, Cerro Azul, Potrero del Llano, Agua Nacida and Alamo. With the exception of the Panuco and Topila districts, these pools represent tracts each of which is controlled by one large company, and in which only a few initial wells have been drilled.

Fig. 138. One of the many basalt dikes which occur in the Mexican oil fields.

In the Mexican fields four distinct formations are encountered: (1) An upper series of fossiliferous Tertiary sandy limes and sandstones, interbedded with limy and sandy clays, the beds varying in thickness from 600 to 1300 feet; (2) an intermediate section, 2000 to 3500 feet thick, of grey marls and shales (called the Mendez marls or Los Esteros beds), the upper part of which is Eocene Tertiary and the lower Upper Cretaceous; and (3) the San Felipe or Valles beds of limestone shells 200 to 800 feet thick alternating with blue and brown shales. These lie upon (4) a massive blue-grey limestone (Tamasopa) formation, at least 3000 feet thick, fossiliferous in its upper portion, of Lower Cretaceous age (Figs. 136 and 137).

Most of the large wells drilled up to the summer of 1915 are located where there exists a significant combination of both favorable anticlinal or dome structure with pronounced fracturing of the formations (Fig. 139). These fractures (sometime faults of relatively small throw)

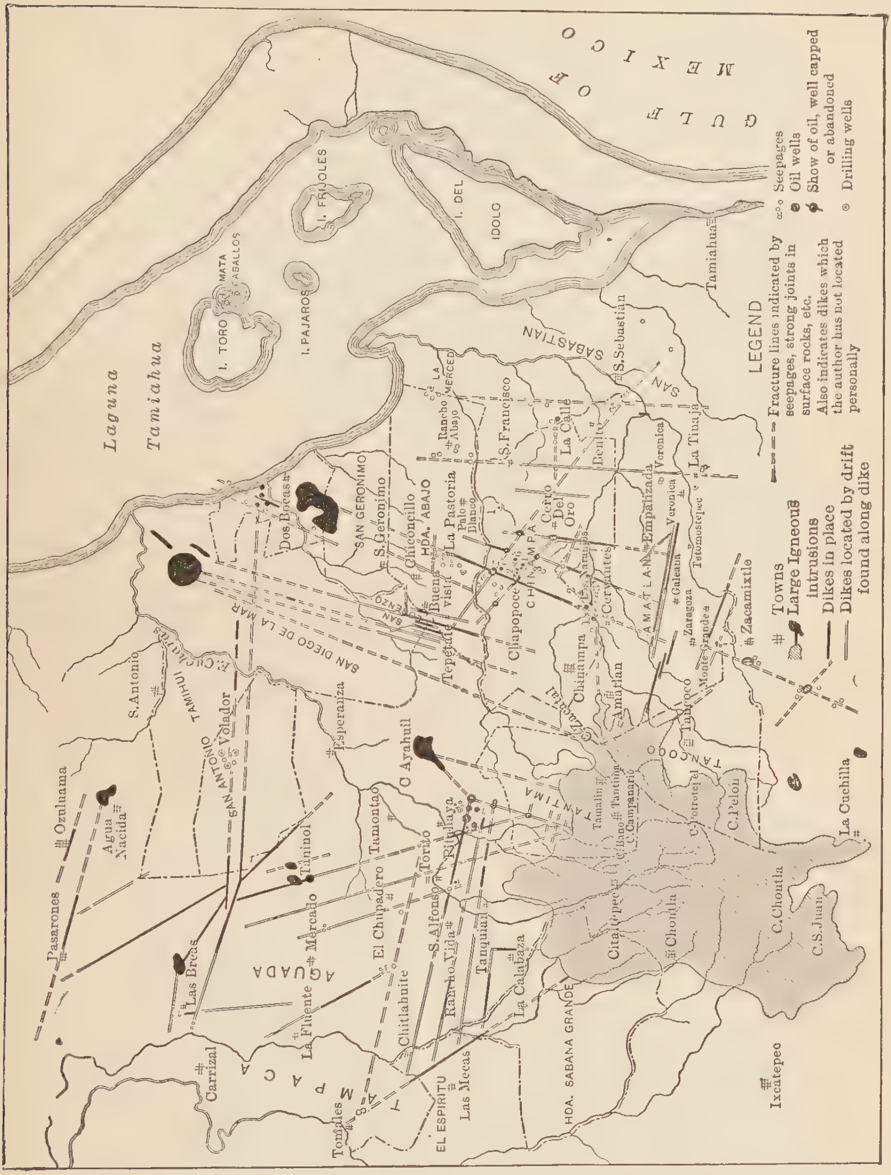

FIG. 139. Map of a portion of the Mexican oil field, showing the relation of the principal igneous intrusions to oil accumulation as evidenced by seepages and large gushers which have been drilled at Dos Bocas, Juan Casiano, and Los Naranjos.

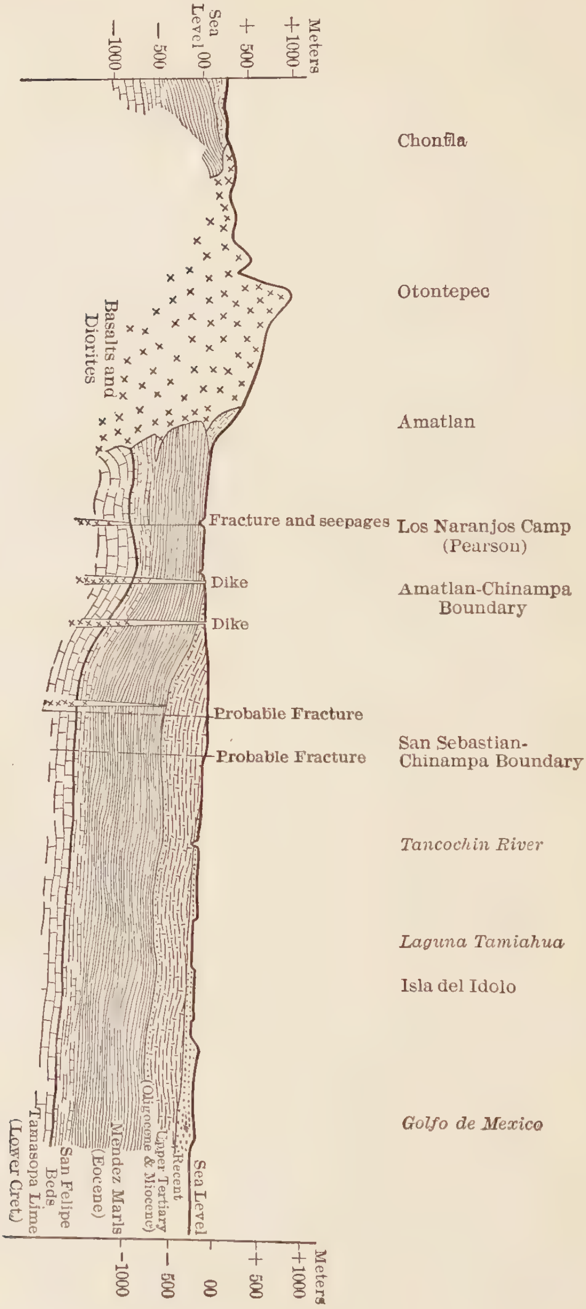

Fig. 140. Diagrammatic vertical section across lower part of Fig. 139.

are usually accompanied by basaltic intrusions (Fig. 140) and seepages of asphalt and gas. The Panuco field (except at one point north of the river in the Tampalache area) is covered by about 100 feet of alluvial sediments, but drilling has shown that the same conditions exist and have influenced the oil accumulation here as in other parts of the Mexican fields.

There has been faulting in connection with some of these anticlinal structures, especially those nearer the mountains. One set of folds becomes broader and less frequent to the eastward. There is another system of relatively well-marked folds in the vicinity of Otontepec, such as those at Potrero del Llano and Los Naranjos. This folding was caused by lateral thrust and probably certain vertical stresses incidental to the formation of the Sierra Madre Mountains to the west. These made lines of weakness in the formations, through which, during late Tertiary time, other igneous rocks were intruded. This is shown by Fig. 139, which is a map of the central part of the fields in which many of the main basalt dikes have been located.

A study of this map will reveal a number of interesting relations, for instance, the general agreement between the strike of the sedimentary formations and that of the main dikes in the coastal portion of the fields. A reference to the sketch map (Fig. 136), showing the areal geology of the Mexican field, fails to reveal any locality where the Tamasopa lime or even the San Felipe beds have been thrust up to the surface by intrusives, as claimed by some of the earlier writers. The authors know of no instance where pronounced doming has been caused by the upthrust of dikes or so-called "plugs" of basalt. Some very local distortion and faulting has been caused at certain places, but on the other hand, there are cases where the sedimentaries actually dip toward large igneous bodies from all sides.

Again referring to Fig. 139 it will be seen that the fields at Juan Casiano, Los Naranjos, Dos Bocas (Figs. 141) and Panuco (Fig. 144) are all located at the intersection of strong fractures, where such intersections occur on anticlinal folds. Intersections of strong fractures are frequently accompanied and marked at the surface by conical basalt peaks, which usually represent the "mushrooming" of an igneous neck intrusion. Wells drilled close to the contact at several of these conical hills have disproved the theory advanced by one geologist that they were "plugs" of conical shape. Wells started close to the contact have been drilled into the oil formation at more than 2000 feet in depth, without encountering any further basalt or any violent distortion.

Fracture intersections, where the resistance was less, have been followed by the magma, so that the dikes are enlarged at these points (Fig. 139). At other places cone-shaped hills occur, along the line of projection from some fracture or dike, but with no sign of basalt at the surface, and no evidence of violent folding. The formations at such places seem to be in place, yet are considerably harder than the surrounding district. It is quite probable that some such intersections, not filled to the surface with basalt, offered a channel for the circulation of underground water more or less hot or highly mineralized, which metamorphosed the sedimentary formations in the immediate vicinity.

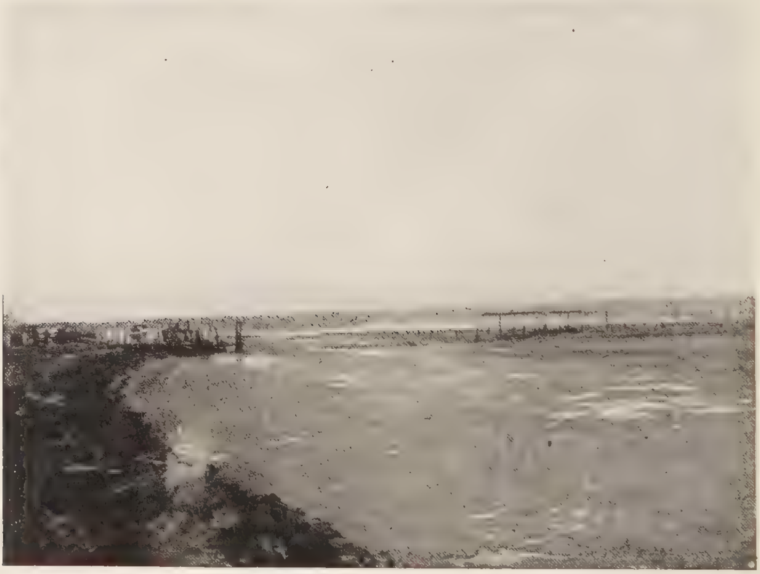

FIG. 141. The Dos Bocas well yielding great quantities of hot water after flowing oil for several months.

One notable example of this is Cerro de Zaragosa, between Amatlan and Zacamixtle. This has every appearance of being a typical basalt peak, yet examination failed to show any basalt on its sides, which are composed of Upper Tertiary formations. And yet the peak is directly in line with a main series of dikes extending from near Dos Bocas to Zacamixtle, through Juan Casiano and Los Naranjos.

The oil in these fields is found in a porous and usually fractured limestone (sometimes shale) near the top of the Tamasopa limestone

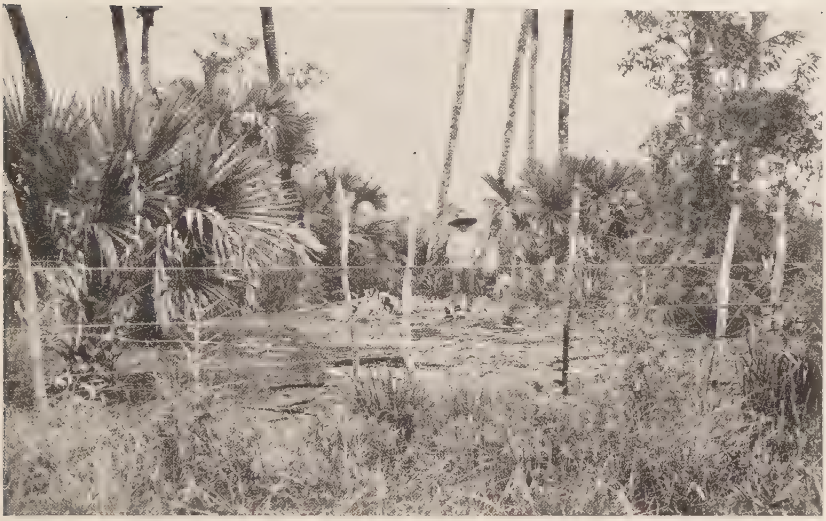

FIG. 142. Large asphalt seepage in the Mexican oil fields. District of Aguada, State of Vera Cruz.

FIG. 143. Small asphalt seepage in Mexican oil fields. South of Ozulouama.

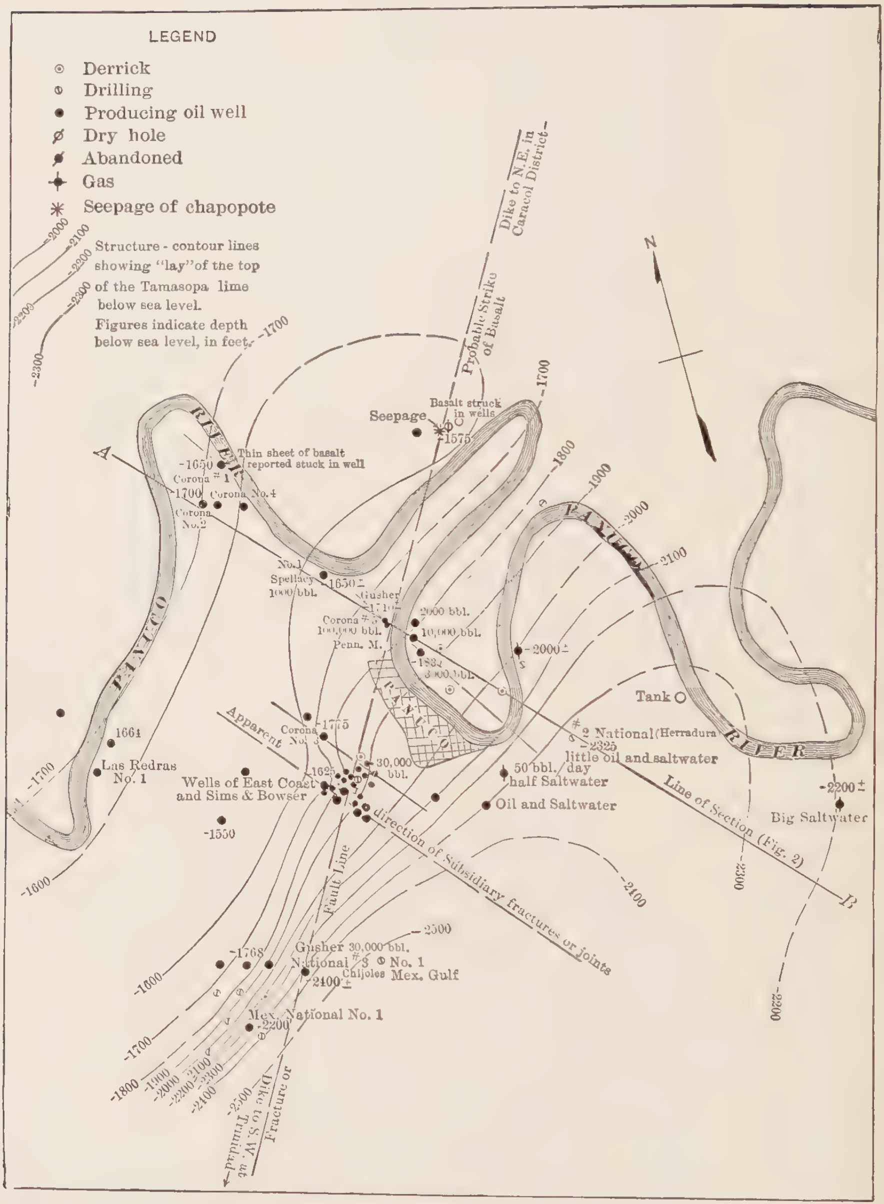

FIG. 144. Isobath map of the Panuco oil pool, as indicated by well logs, with the location of the principal wells.

formation. Although a few shows, and in some cases considerable salt water, have been encountered, no oil in large quantities has ever been found as yet by drilling deeper into the lime.

Oil is also found, particularly in the "gusher" wells, in the broken lime "shells" and blue shale of the San Felipe series (Fig. 145), usually under conditions indicating strong fracturing and jointing. Oil is not found in the homogeneous marls overlying the San Felipe, although these marls are more or less petroliferous throughout. However, in drilling near dikes and fractures where seepages (Figs. 138, 142 and 143) occur at the surface, shows of gas and heavy oil are often encountered in the hole all the way down.

TENTATIVE CORRELATION OF THE TERTIARY AND CRETACEOUS FORMATIONS OF NORTHEASTERN MEXICO

Tertiary	Pliocene		Quaternary and recent deposits	
	Miocene		Tuxpan	Later Tertiary: Clays, limestones and sands. 700′ ±
	Oligocene		San Fernando (yellow clays, limestones and sands)	
	Eocene		Alazan shales Mendez shales (in part)	Cretaceous-Eocene: Shales. 3000′ ±
Cretaceous	Upper		Papagallos shales Mendez shales (in part)	
			San Felipe limestones and shales	Upper Cretaceous: Limestones and shales. 500′ ±
			Cardenas	
	Lower	Middle	Tamasopo limestone	Lower Cretaceous: Limestones. 3000′ ±
		Lower	El Abra limestone	

Garfias, V. R., Oil Region of Northern Mexico, Econ. Geol. of Apr.–May, 1915. Effect of Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico, Jour. of Geology, Vol. 30, 666.
Ordonez, E., The Oil Fields of Mexico, Bull. A. I. M. E., Oct., 1914.
Dumble, E. T., The Occurrences of Petroleum in Eastern Mexico as contrasted with those in Texas and Louisiana, Bull. A. I. M. E., August, 1915.
DeGolier, E., The Furbero Oil Field, Mexico, Bull. A. I. M. E., Sept., 1915.

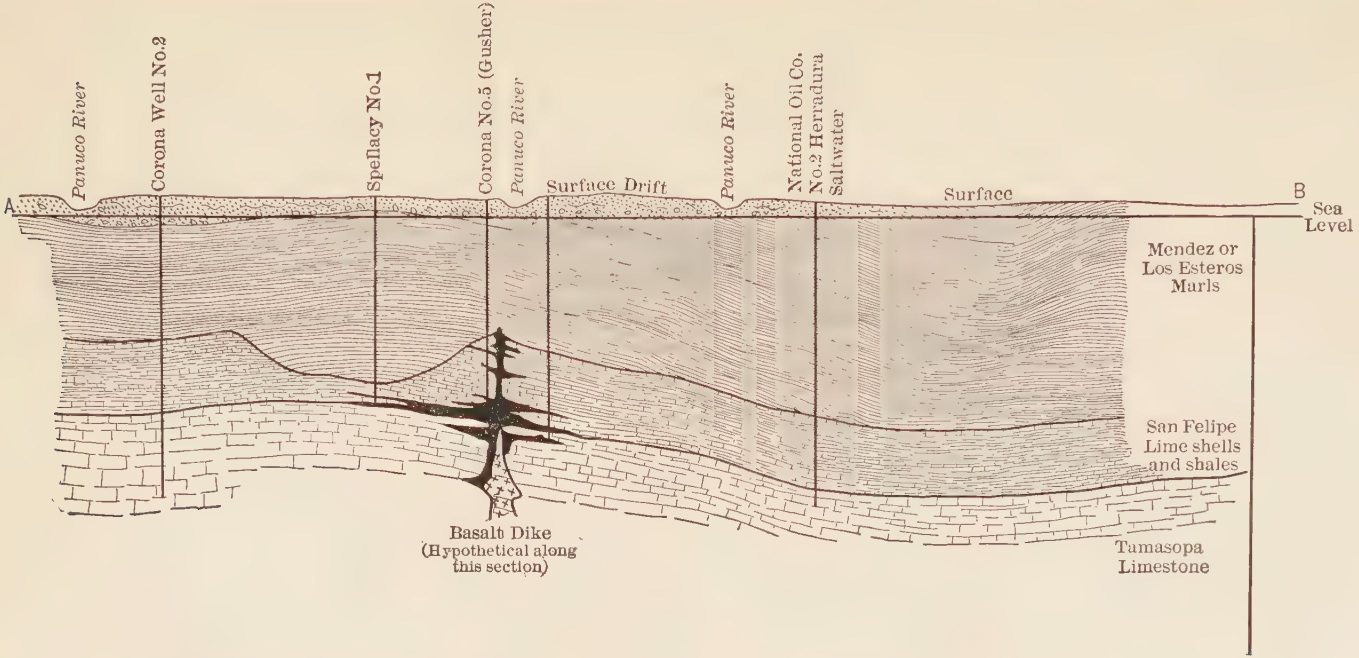

Fig. 145. Hypothetical section through the Panuco Field, Mexico, along the line *A–B* (Fig. 144).

The oil found in the northern part of the developed district (Ebano, Panuco, Topila, etc.) is accompanied by comparatively little gas, varies in gravity from 10° to 15° B., and is of fuel oil grade. South of the Panuco River district, a higher grade oil is produced, from 18° to 27° B. This is given a first cut or is "topped" for its gasoline content before being sold for fuel. The new transformation processes[1] will undoubtedly give a larger percentage of high gravity products.

Because of the great "shut-in" production, only the smaller portion of the area described has been prospected. Additional railroads, which will be built when political conditions become more settled, will open up the less accessible portions of the field, further from the coast. The area between Tampico and Soto La Marina to the north is being developed by the Dutch-Shell interests at San José de las Rusia. However, a large proportion of the more obviously promising properties are already held by large companies.

Tehuantepec Field

These fields border on the Gulf of Campeche, and were first exploited by the Pearson interests (English), who built their refinery at Minatitlan for handling the oil which they produced. The oil occurs principally around saline domes similar to those of the Gulf Coast field of the United States. The structure is, however, complicated by folding. The producing formations are reported to be of Tertiary age.

The oil varies in composition according to the relation of the producing well to the large mountain folds. Some of it is reported to be of high gravity and good quality. The production is small, and operations are somewhat desultory, owing to the prolific fields which have been developed to the north in the vicinity of Tampico and Tuxpam.

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[1] Rittmann, Dutton and Dean, U. S. Bureau of Mines Bull. 119.

CHAPTER XXIII

THE OIL MARKET AND THE FUTURE SUPPLY

Relation between the prices of the several pools. — The relation between the market price of crude oils from the various pools is dependent upon three main factors, which may be stated as follows:

(1) The quality of the oil.
(2) The price obtainable for its products, and their relative cost of production.
(3) The self-interest of the price-making companies.

(1) *The quality of the oil.* — Fundamentally the basis of the varying prices for different crude oils is their quality, that is to say, the percentage of high-priced products which may be recovered from them at the refinery. Or if it is a fuel oil, the governing factors are the percentage of sulphur and the amount of gasoline which may be recovered by preliminary "topping," as well as the adaptability of the oil for use in internal combustion engines. As a matter of fact, in any particular oil producing district, refineries are built or adapted for refining certain grades of oil which are produced in near-by fields. Later a pool may be brought in which produces a higher grade oil than the regular pipe line runs. If there is no competition between refineries, no premium is paid for the better oil over the ruling price for the run of the district, unless a sufficient amount is finally produced to lead the nearest refinery to fear that it may be piped or shipped elsewhere.

(2) *The price obtainable for the products.* — Not only the general quality of an oil, but a high percentage of certain constituents may result in its commanding a premium over other near-by oils. For example, oil produced from the Milltown pool near Pittsburg has a special sale for use in making vaseline and other medicinal oils. Some wells in California yield an oil high in naphthalene. The price that can be obtained is affected by the demand for the several petroleum products. The increased demand for wax, medicinal oil and gasoline has been especially marked. In fact, the price of oil is influenced to an appreciable degree by the automobile market. The great increase in the demand for gasoline for automobiles is shown by the fact that, while in 1909 there were 127,287 automobiles manufactured in the United States, in 1914 the number reached 573,114, more than four

times as many. Figs. 146 and 147 show the relative increase of production of oil and of automobiles.[1]

In a district where there is a good market for fuel oil and a poor market for lubricating oils, the residue from the refineries which contains a high percentage of lubricants may still be sold merely for fuel oil. This is because the margin of difference between the net returns from the manufacture and sale of lubricants, after transportation costs to the market are paid, is not enough to warrant its use for higher utilization.

Of course, the greatest market for the products of petroleum is in the Eastern and Middle Western States, and at the seaboard, while Pennsylvania grade crude oil may command a price of $2.60 per barrel, and Cushing oil but $1.55 per barrel, without a corresponding proportion between the quantities of similar products produced from each. Nevertheless, the fact remains that the production in Oklahoma has exceeded the consumption of near-by states, while in the Appalachian field the production is less than the needs of the Eastern states. A large part of the difference in the market prices of the two grades of crude oil is due to the cost of transportation — either of the crude to refineries or of the refinery products to points of consumption.

So we have a relatively high-grade oil produced in Wyoming which was recently sold at $0.50. In the San Juan district in Utah, the operating and producing costs are so high that operators cannot afford to operate.

In Mexico government and state taxes have imposed a burden on the oil produced which for a time prevented its general export in competition with United States fuel oils of equal or poorer quality. In the first few years of production the lack of refining facilities prevented the gasoline content from being recovered from the lighter Mexican crude oils which were exported and sold as fuel. Naturally a great deal of this light fraction was lost by weathering.

(3) *The interest of the price-making companies.* — At one time in the history of oil development in the United States, the leading oil interest, which largely controlled pipe-lines, refineries and market facilities, was able to manipulate the market price of crude oil to its own advantage. This power has been curtailed more than has been generally believed by the opening of new fields, and the building of strong independent refineries and pipe lines. As evidence of this the history of the Cushing pool in Oklahoma and its effect upon prices may be cited. The price of oil declined and rose again in close correlation with the rise and decline of the production of that pool. In fact, it is frequently the case

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[1] Brooks, B. T., The Gasoline Supply, Jour. Indus. Eng. Chem. 7, 176.

that the independent refineries offer higher and higher premiums and so force an advance by the leading company, or, by cutting prices, lead to a reduction.

It is, however, true that for a time a pool may suffer through having but one pipe line[1] connecting it with a refinery, as at Healdton, Okla. This is particularly true when there is a general over-production of another higher grade oil, as was there the case. The oil in such a pool may not be greatly inferior to more favorably situated pools, but so long as the refineries can fill their needs with better oil, the price that is paid for the oil from the isolated pool is less than its quality would seem to merit.

Stored oil and its influence. — The crude oil stocks of the different fields of the country (the oil in tanks) is looked upon as a barometer of the relative over-production or under-production existing at any time. However, its effect is discounted and the market price of oil is apt to advance or decline before there is much change in the amount of tanked oil. For instance, the price of oil dropped in 1914 when only the first large wells had been drilled at Cushing, and there was as yet no real over-production except locally. It rose again when Cushing's daily production began to fall off, even though the amount of tanked oil was larger than it had been for years, and was still being increased. The size of oil stocks as an indication of price may therefore be likened to a gage which has a considerable "lag." This is the result of good business foresight and the same practice is not considered unfair or improper in other industries.

Effect of international commerce. — The effect of international commerce upon the oil market in this country is much less than might be supposed. The history of the drop in the early part of 1914 in close correlation with the bringing in of the Cushing pool, and the corresponding rise in 1915, as this pool declined, does not show the reactions which might have been expected, if the stopping of oil shipments by the European war, in August, 1914, had been considered a serious menace to the market. The fact that the course of the quotations for the shares of the leading oil companies in this country has been only slightly affected by the varying fortunes of the war is an indication that this element is of less importance than is the status of the various producing districts.

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[1] Pipe-line Transportation of Petroleum, Report of the Federal Trade Commission, Feb. 28, 1916.

Production, Transportation and Marketing of Petroleum. Senate Document 13, 64th Congress, 1st Session.

There are two natural limits to the price of petroleum as follows:

(*a*) Petroleum cannot increase in price much past the cost of producing shale oil. America has enormous supplies of cheaply quarried or mined oil shales and sands. This is likely to hold oil down to a point probably not much above $3.00 per barrel (Pennsylvania grade). In fact, a great deal of petroleum will have to be left in the ground until after surface extracted oil has become dearer as the supply nears exhaustion.

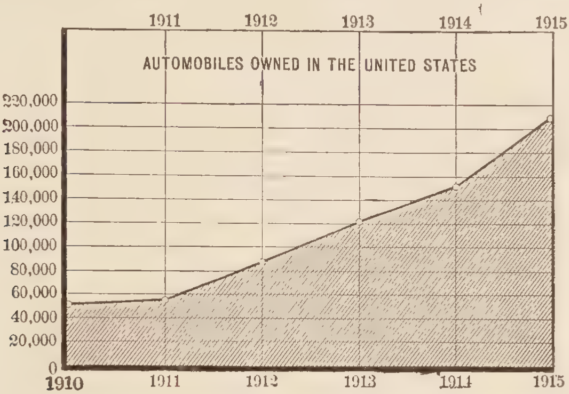

FIG. 146.

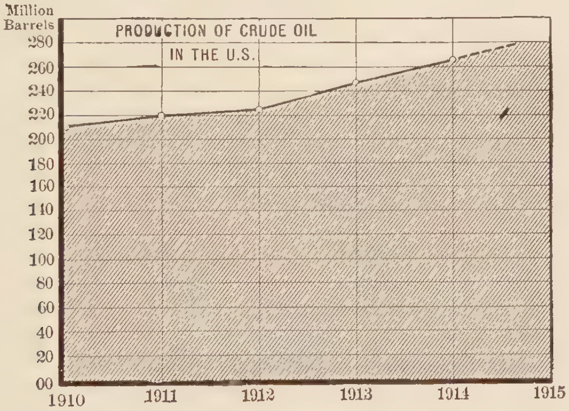

FIG. 147.

(*b*) Fuel oil cannot advance very much over the price of that amount of coal which will produce the same amount of heat at the point of consumption, plus the saving in handling. Its supply must be large and reliable to reach this level.

The question, "How long before the supply[1] of oil and gas will be exhausted?" should be answered, "Never."[2] The history of the development of oil and gas, like that of coal, will be that thinner and thinner, deeper and deeper oil sands will be in turn developed. Like coal, there will also be the gradual resort to regions where a larger and larger percentage of dry holes is inevitable.

The consequent slow rise in price will cause oil gradually to be given up in its several uses, as its cost becomes higher than that of its potential substitutes.[3] Its uses will thus become gradually narrowed, though there will still be plenty of oil and gas to be had, if anyone is willing to pay the price.

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[1] Senate Document 310, 64th Congress, 1st session.

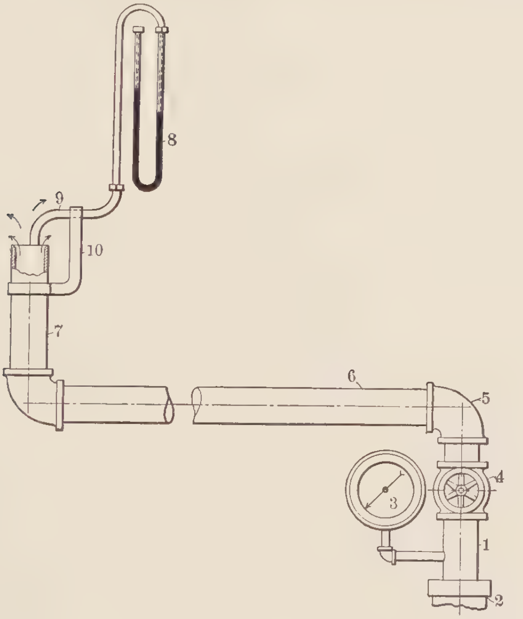
[2] Arnold, R. Conservation of the Oil and Gas Resources of the Americas. Econ. Geol., Vol. XI, pp. 203–222 and 299–326.

[3] Johnson, R. H. Legal and Economic Factors in the Conservation of Oil and Gas. Natural Gas Journal, February, 1916.

APPENDIX

OUTPUT OF GAS WELLS MEASURED BY THE PITOT TUBE

The Pitot tube is an instrument consisting of a small tube, one end of which is bent at right angles, which is used to determine the velocity of moving gas or fluid by means of its momentum. The bent end of the tube is inserted in the pipe which conveys the gas to be measured between one-third and one-fourth the diameter of the pipe from the outer edge, so that the plane of the opening is at right angles to the flow of gas. A U-gage is connected to the other end, and is half filled with mercury or water. A spring-pressure gage should be used if the flow pressure is over five pounds to the square inch. The difference in level, or the distance between the high and low side of the fluid in the U-gage measures the pressure.



Courtesy S. S. Wyer

FIG. 148.

Gas Pressure Units

Equivalent at 32° F.

(From S. S. Wyer)

1 lb. per sq. in. =
2.309 ft. water.
27.68 in. water.
2.035 in. mercury.
51.71 mm. mercury.
16.00 oz. per sq. in.
0.068 atmosphere.

1 atmosphere =
29.92 in. mercury.
33.9 ft. water.
14.7 lbs. per sq. in.

1 in. mercury =
13.6 in. water.
0.49 lbs. per sq. in.
7.84 oz. per sq. in.
0.033 atmosphere.

1 in. water =
0.073 in. mercury.
0.036 lbs. per sq. in.
0.57 oz. per sq. in.
0.002 atmosphere.

1 oz. per sq. in. =
1.73 in. water.
0.127 in. mercury.
0.062 lbs. per sq. in.

Flow of Natural Gas. Inside Diameter of Pipe = 1 Inch

Observed pressure by mercury gage, in inches.	Observed pressure by water gage, in inches.	Observed pressure by pressure gage, in lbs. per square inch.	Cubic feet per day.	Observed pressure by mercury gage, in inches.	Observed pressure by water gage, in inches.	Observed pressure by pressure gage, in lbs. per square inch.	Cubic feet per day.
....	0.1	0.0036	12,390	10.17	....	5.0	436,200
....	0.2	0.0073	17,560	11.18	....	5.5	456,200
....	0.3	0.0109	21,480	12.20	....	6.0	473,750
....	0.5	0.0182	27,720	13.21	....	6.5	489,840
0.05	0.7	0.0254	32,820	14.23	....	7.0	505,920
0.7	1.0	0.0364	39,210	15.25	....	7.5	522,010
0.11	1.5	0.0545	48,030	16.26	....	8.0	538,500
0.15	2.0	0.0727	55,340	18.30	....	9.0	565,970
0.22	3.0	0.109	67,910	20.33	....	10.0	589,270
0.29	4.0	0.145	78,410	24.39	....	12.0	633,340
0.37	5.0	0.182	87,670	28.46	....	14.0	675,000
0.52	7.0	0.254	103,500	32.53	....	16.0	713,550
0.74	10.0	0.3636	123,000	36.60	....	18.0	748,650
1.02	13.75	0.50	146,220	40.66	....	20.0	779,350
1.52	20.62	0.75	175,350	50.81	....	25.0	845,150
2.03	27.5	1.00	201,800	61.00	....	30.0	902,180
3.05	41.25	1.5	247,840	71.16	....	35.0	954,820
4.07	55.0	2.0	285,130	......	....	40.0	989,680
5.08	68.75	2.5	316,500	......	....	50.0	1,036,700
6.10	82.50	3.0	344,350	......	....	45.0	1,072,000
7.12	96.25	3.5	370,000	......	....	55.0	1,106,880
8.13	110.0	4.0	393,000	......	....	60.0	1,137,600
8.15	....	4.5	415,270				

(Adapted from Thompson, A. Beeby, Petroleum Mining.)

For temperature of flowing gas where observed of 30°, 40°, 50°, 60° F., add 4, 3, 2, 1 per cent respectively.

To change the result by this table to that for any other specific gravity of gas than 0.6, multiply by $\sqrt{\frac{0.6}{\text{Sp. gr. gas}}}$.

Should 98 per cent alcohol be used in gage, multiply the readings by 0.8 to reduce to water value.

Should .75 specific gravity kerosene be used in gage, multiply the readings by .75 to reduce to water value.

MULTIPLIERS FOR PIPE OF DIAMETERS OTHER THAN 1 INCH

The number of cubic feet of gas per 24 hours of a specific gravity of 0.6 (air equaling 1.0) that will flow from the mouth of a well or pipe is given in the following table. The pressure of the container is taken as four ounces above an assumed atmospheric pressure of 14.4 pounds to the square inch, and the temperature of the flowing gas and the container assumed to be 60° F. If the diameter of the pipe is other than one inch, multiply the discharge value given in the table by the square of the actual diameter of the pipe.

Size of opening, diameter n inches.	Multiplier.	Size of opening, diameter in inches.	Multiplier.	Size of opening, diameter in inches.	Multiplier.	Size of opening, diameter in inches.	Multiplier.	Size of opening, diameter in inches.	Multiplier.
$\frac{1}{16}$	0.0038	1	1.00	4	16.00	6	36.00	8	64.00
$\frac{1}{8}$	0.0156	$1\frac{1}{2}$	2.25	$4\frac{1}{4}$	18.00	$6\frac{1}{4}$	39.00	$8\frac{1}{4}$	68.00
$\frac{1}{4}$	0.0625	2	4.00	5	25.00	$6\frac{5}{8}$	43.90	9	81.00
$\frac{1}{2}$	0.2500	$2\frac{1}{2}$	6.25	$5\frac{3}{16}$	26.90	7	49.00	10	100.00
$\frac{3}{4}$	0.5625	3	9.00	$5\frac{5}{8}$	31.60	$7\frac{1}{4}$	52.50	12	144.00

VARIATION IN VOLUME OF 100 CUBIC FEET (100 PER CENT) OF GAS AT CONSTANT TEMPERATURE UNDER VARIOUS GAGE PRESSURES

Pressure per sq. in.	Volume.	Pressure per sq. in.	Volume.	Pressure per sq. in.	Volume.
0 oz.	100.0%	4 lbs.	78.6%	20 lbs.	42.3%
2	99.1	5	74.6	30	32.8
4	98.3	6	71.0	40	26.8
6	97.5	7	67.7	50	22.7
8	96.7	8	64.7	75	16.8
10	95.9	9	62.0	100	12.8
12	95.1	10	59.5	150	8.9
14	94.3	12	55.0	200	6.8
1 lbs.	93.6	14	51.5	250	5.5
2	88.0	16	47.8	300	4.6
3	83.0	18	44.9	400	3.5

Change in Volume of 1000 Feet of Air or Natural Gas, Owing to Change in Temperature

From Westcott, H. P., Handbook of Natural Gas

The standard is taken at 60° F. and 14.4 inches of mercury plus 0.25 = 14.65 inches of mercury. Absolute zero = 460° F. below freezing = 488° below 60° F. The specific gravity of the natural gas is taken at 0.6, air being 1. The same 1000 cubic feet of gas at 60° F. will measure 1041 cubic feet at 80° and 959 cubic feet at 40°. The percentage of the decrease and increase, below or above 60° F.; the specific gravity of the gas at temperatures below and above 60° F.; also weight of 1000 cubic feet of gas and air at the different temperatures is shown. For each degree there is a change of .002056 in volume.

Degrees, Fahr.	1000 cu. ft. of gas measured at other temperatures than 60° F.	Percentage of loss or gain in 1000 cu. ft.	Spec. gravity of nat. gas being taken at 0.6.	Weight of 1000 cu. ft. of gas at 0.6 sp. gr.	Weight of 1000 cu. ft. of air.
0	877	−12.3	0.6841	58.82	85.97
10	897	−10.3	0.6689	56.41	84.33
20	918	− 8.2	0.6536	54.04	82.69
32	943	− 5.7	0.6362	51.36	80.73
40	959	− 4.1	0.6256	49.68	79.43
50	980	− 2.0	0.6124	47.63	77.77
60	1000	− 0.0	0.6000	45.67	76.12
70	1020	+ 2.0	0.5879	43.78	74.48
80	1041	+ 4.1	0.5763	41.96	72.83
90	1061	+ 6.1	0.5652	40.23	71.19
100	1082	+ 8.2	0.5545	38.56	69.55
110	1102	+10.2	0.5442	36.95	67.90
120	1122	+12.3	0.5343	35.40	66.26
130	1143	+14.3	0.5247	34.10	64.62
140	1163	+16.3	0.5157	32.47	62.98
150	1184	+18.4	0.5067	31.07	61.33
160	1204	+20.4	0.4981	29.72	59.69
170	1225	+22.5	0.4898	28.42	58.05
180	1245	+24.5	0.4818	27.17	56.40
190	1265	+26.6	0.4739	25.94	54.76
200	1285	+28.6	0.4665	24.78	53.12
210	1306	+30.7	0.4591	23.63	51.48
212	1311	+31.1	0.4576	23.41	51.16

Baumé Scale and Specific Gravity Equivalent

Table of Baumé hydrometer readings from 10° to 90° B. with corresponding specific gravity, and also the number of pounds contained in one U. S. gallon at 60° F. From U. S. Bureau of Standards Circular 57.

Baumé°.	Specific gravity.	Pounds in gallon.	Baumé°.	Specific gravity.	Pounds in gallon.	Baumé°.	Specific gravity.	Pounds in gallon.
10	1.0000	8.33	37	0.8383	6.99	64	0.7216	6.01
11	0.9929	8.27	38	0.8333	6.94	65	0.7179	5.98
12	0.9859	8.21	39	0.8284	6.90	66	0.7143	5.96
13	0.9790	8.15	40	0.8235	6.86	67	0.7107	5.92
14	0.9722	8.10	41	0.8187	6.82	68	0.7071	5.89
15	0.9655	8.04	42	0.8140	6.78	69	0.7035	5.86
16	0.9589	7.99	43	0.8092	6.74	70	0.7000	5.83
17	0.9524	7.93	44	0.8046	6.70	71	0.6965	5.80
18	0.9459	7.88	45	0.8000	6.66	72	0.6931	5.77
19	0.9396	7.83	46	0.7955	6.62	73	0.6897	5.74
20	0.9333	7.77	47	0.7910	6.59	74	0.6863	5.71
21	0.9272	7.72	48	0.7865	6.55	75	0.6829	5.69
22	0.9211	7.67	49	0.7821	6.51	76	0.6796	5.66
23	0.9150	7.62	50	0.7778	6.48	77	0.6763	5.63
24	0.9091	7.57	51	0.7735	6.44	78	0.6731	5.60
25	0.9032	7.52	52	0.7692	6.40	79	0.6699	5.58
26	0.8974	7.47	53	0.7650	6.37	80	0.6667	5.55
27	0.8917	7.42	54	0.7609	6.33	81	0.6635	5.52
28	0.8861	7.38	55	0.7568	6.30	82	0.6604	5.50
29	0.8805	7.33	56	0.7527	6.27	83	0.6573	5.47
30	0.8750	7.29	57	0.7487	6.23	84	0.6542	5.45
31	0.8696	7.24	58	0.7447	6.20	85	0.6512	5.42
32	0.8642	7.20	59	0.7407	6.17	86	0.6482	5.40
33	0.8589	7.15	60	0.7368	6.13	87	0.6452	5.37
34	0.8537	7.11	61	0.7330	6.10	88	0.6422	5.35
35	0.8485	7.07	62	0.7292	6.07	89	0.6393	5.32
36	0.8434	7.02	63	0.7254	6.04	90	0.6364	5.30

Degrees Baumé may be converted to specific gravity by adding 130 to the Baumé degrees and dividing this by 140.

CHANGE OF BAUMÉ SCALE OF GRAVITY WITH TEMPERATURE

All gravities are based on a temperature of 60° F., but owing to the inconvenience of having fluids exactly at 60 degrees temperature when tested, this table is computed to give the corresponding gravity at any other common temperature. Heavy oils should be heated so that the hydrometer will move in them freely. In reading disregard the capillary attraction up the stem of the hydrometer. From U. S. Bureau of Standards Circular 57.

Gravity, B.	Temperatures F.											
	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
20	21.5	21.2	20.8	20.6	20.3	20.0	19.7	19.4	19.1	18.9	18.6	18.3
21	22.5	22.2	21.8	21.6	21.3	21.0	20.7	20.4	20.1	19.8	19.6	19.3
22	23.5	23.2	22.8	22.6	22.3	22.0	21.7	21.4	21.1	20.8	20.5	20.3
23	24.6	24.2	23.9	23.6	23.3	23.0	22.7	22.4	22.1	21.8	21.5	21.2
24	25.6	25.2	24.9	24.6	24.3	24.0	23.7	23.4	23.1	22.8	22.5	22.2
25	26.6	26.2	25.9	25.6	25.3	25.0	24.7	24.4	24.0	23.8	23.5	23.2
26	27.6	27.2	26.9	26.6	26.3	26.0	25.7	25.4	25.0	24.8	24.4	24.2
27	28.6	28.3	28.0	27.6	27.3	27.0	26.7	26.4	26.0	25.7	25.4	25.1
28	29.7	29.3	29.0	28.6	28.3	28.0	27.7	27.4	27.0	26.7	26.4	26.1
29	30.7	30.4	30.0	29.7	29.3	29.0	28.7	28.3	28.0	27.7	27.4	27.0
30	31.7	31.4	31.0	30.7	30.3	30.0	29.7	29.3	29.0	28.7	28.4	28.0
31	32.8	32.4	32.0	31.7	31.3	31.0	30.6	30.3	30.0	29.7	29.3	29.0
32	33.8	33.4	33.0	32.7	32.4	32.0	31.6	31.3	31.0	30.7	30.3	30.0
33	34.8	34.4	34.1	33.7	33.4	33.0	32.6	32.2	31.9	31.7	31.2	30.9
34	35.8	35.4	35.1	34.7	34.4	34.0	33.6	33.2	32.9	32.6	32.2	31.9
35	36.9	36.5	36.2	35.7	35.4	35.0	34.6	34.2	33.9	33.5	33.1	32.9
36	37.9	37.5	37.2	36.7	36.4	36.0	35.6	35.2	34.9	34.5	34.1	33.9
37	39.0	38.5	38.2	37.8	37.4	37.0	36.6	36.2	35.8	35.5	35.1	34.8
38	40.0	39.5	39.2	38.8	38.4	38.0	37.6	37.2	36.8	36.5	36.1	35.8
39	41.0	40.6	40.2	39.8	39.4	39.0	38.6	38.2	37.8	37.5	37.1	36.7
40	42.1	41.6	41.2	40.8	40.4	40.0	39.6	39.2	38.8	38.5	38.1	37.7
41	43.1	42.7	42.3	41.8	41.4	41.0	40.6	40.2	39.8	39.4	39.0	38.6
42	44.1	43.7	43.3	42.8	42.4	42.0	41.6	41.2	40.8	40.4	40.0	39.6
43	45.2	44.8	44.3	43.9	43.4	43.0	42.6	42.2	41.7	41.3	40.9	40.5
44	46.2	45.8	45.3	44.9	44.4	44.0	43.6	43.1	42.7	42.3	41.9	41.5
45	47.2	46.8	46.3	45.9	45.4	45.0	44.6	44.1	43.7	43.2	42.8	42.5
46	48.3	47.8	47.3	46.9	46.4	46.0	45.6	45.1	44.7	44.2	43.8	43.5
47	49.3	48.8	48.4	47.9	47.5	47.0	46.6	46.1	45.7	45.2	44.8	44.4
48	50.4	49.9	49.4	48.9	48.5	48.0	47.6	47.1	46.7	46.2	45.8	45.4
49	51.4	51.0	50.5	50.0	49.5	49.0	48.5	48.1	47.6	47.2	46.7	46.3
50	52.5	52.0	51.5	51.0	50.5	50.0	49.5	49.1	48.6	48.2	47.7	47.3
51	53.6	53.0	52.5	52.0	51.5	51.0	50.5	50.1	49.6	49.1	48.6	48.2
52	54.6	54.2	53.5	53.0	52.5	52.0	51.5	51.1	50.6	50.1	49.6	49.2
53	55.7	55.2	54.6	54.0	53.5	53.0	52.5	52.0	51.5	51.0	50.5	50.1
54	56.7	56.2	55.6	55.0	54.5	54.0	53.5	53.0	52.5	52.0	51.5	51.0
55	57.8	57.2	56.6	56.1	55.5	55.0	54.5	54.0	53.4	52.9	52.4	51.9
56	58.8	58.2	57.6	57.1	56.5	56.0	55.5	55.0	54.4	53.9	53.4	52.9
57	59.9	59.3	58.7	58.1	57.6	57.0	56.5	55.9	55.4	54.8	54.3	53.8
58	60.9	60.3	59.7	59.1	58.6	58.0	57.5	56.9	56.4	55.8	55.3	54.8
59	62.0	61.4	60.8	60.2	59.6	59.0	58.5	57.9	57.3	56.8	56.2	55.7
60	63.0	62.4	61.8	61.2	60.6	60.0	59.4	58.9	58.3	57.8	57.2	56.7
61	64.1	63.5	62.8	62.2	61.6	61.0	60.4	59.8	59.2	58.7	58.1	57.6
62	65.1	64.5	63.8	63.2	62.6	62.0	61.4	60.8	60.2	59.7	59.1	58.6
63	66.2	65.5	64.9	64.2	63.7	63.0	62.4	61.8	61.2	60.6	60.0	59.5
64	67.2	66.5	65.9	65.2	64.7	64.0	63.4	62.8	62.2	61.6	61.0	60.4

CHANGE OF BAUMÉ SCALE OF GRAVITY WITH TEMPERATURE. — *Continued*

Gravity, B.	Temperatures F.											
	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
65	68.3	67.6	66.9	66.2	65.7	65.0	64.4	63.8	63.1	62.6	61.9	61.3
66	69.3	68.6	67.9	67.2	66.7	66.0	65.4	64.8	64.1	63.6	62.9	62.3
67	70.4	69.7	69.0	68.3	67.7	67.0	66.3	65.7	65.1	64.5	64.8	63.2
68	71.4	70.7	69.9	69.3	68.7	68.0	67.3	66.7	66.1	65.4	64.8	64.2
69	72.5	71.8	71.0	70.4	69.7	69.0	68.3	67.6	67.1	66.4	65.7	65.1
70	73.5	72.8	72.0	71.4	70.7	70.0	69.3	68.6	68.1	67.4	66.7	66.1
71	74.6	73.9	73.1	72.5	71.7	71.0	70.3	69.5	69.0	68.3	67.6	67.0
72	75.6	74.9	74.1	73.5	72.7	72.0	71.3	70.5	70.0	69.3	68.6	68.0
73	76.7	76.0	75.2	74.5	73.7	73.0	72.3	71.5	70.9	70.2	69.4	68.9
74	77.7	77.0	76.2	75.5	74.7	74.0	73.3	72.5	71.9	71.2	70.4	69.9
75	78.8	78.1	77.3	76.5	75.7	75.0	74.3	73.5	72.8	72.1	71.4	70.8
76	79.9	79.1	78.3	77.5	76.7	76.0	75.3	74.5	73.8	73.1	72.4	71.7
77	81.0	80.1	79.3	78.6	77.7	77.0	76.3	75.5	74.8	74.0	73.3	72.6
78	82.0	81.1	80.3	79.6	78.7	78.0	77.3	76.5	75.8	75.0	74.3	73.6
79	83.1	82.2	81.4	80.6	79.7	79.0	78.3	77.4	76.7	75.9	75.2	74.5
80	84.1	83.2	82.4	81.6	80.8	80.0	79.3	78.4	77.7	76.9	76.2	75.5
81	85.2	84.3	83.5	82.6	81.8	81.0	80.2	79.4	78.6	77.8	77.1	76.4
82	86.2	85.3	84.5	83.6	82.8	82.0	81.2	80.4	79.6	78.8	78.1	77.3
83	87.3	86.4	85.6	84.7	83.8	83.0	82.2	81.4	80.6	79.8	79.0	78.2
84	88.4	87.4	86.6	85.7	84.8	84.0	83.2	82.4	81.6	80.8	80.0	79.2
85	89.5	88.5	87.6	86.7	85.8	85.0	84.2	83.3	82.6	81.7	80.8	80.1
86	90.5	89.5	88.6	87.7	86.8	86.0	85.2	84.3	83.6	82.7	81.8	81.1
87	91.6	90.6	89.7	88.8	87.8	87.0	86.2	85.3	84.4	83.6	82.8	82.0
88	92.7	91.7	90.7	89.8	88.8	88.0	87.2	86.3	85.4	84.6	83.6	82.9
89	93.7	92.8	91.8	90.9	89.9	89.0	88.2	87.3	86.4	85.5	84.6	83.8
90	94.7	93.8	92.8	91.9	90.9	90.0	89.1	88.3	87.4	86.5	85.6	84.8

DEPTH OF STRATA BELOW A HORIZONTAL SURFACE AT A DISTANCE OF 100 FEET FROM THE OUTCROP, AND ALONG THE DIP, THE THICKNESS OF A BED HAVING AN OUTCROP 100 FEET WIDE

Dip, degrees.	Depth.	Thickness.	Dip, degrees.	Depth.	Thickness.
1	1.75	1.75	16	28.68	27.56
2	3.49	3.49	17	30.57	29.23
3	5.24	5.23	18	32.49	30.90
4	6.99	6.97	19	34.43	32.55
5	8.75	8.71	20	36.40	34.20
6	10.51	10.45	21	38.39	35.83
7	12.28	12.19	22	40.40	37.46
8	14.05	13.92	23	42.45	39.07
9	15.84	15.64	24	44.52	40.67
10	17.63	17.36	25	46.63	42.26
11	19.44	19.08	26	48.77	43.83
12	21.26	20.79	27	50.95	45.40
13	23.09	22.49	28	53.17	46.94
14	24.93	24.19	29	55.43	48.48
15	26.80	25.88	30	57.74	50.00

(Modified from Redwood and Eastlake.)

RELATIVE HEAT UNIT AND CANDLE POWER HOUR COST

Courtesy S. S. Wyer.

		Name.	Gross heat units per unit.	Price per unit.	What one dollar will buy.				
					Number heat units.	Number candle power hours service.		Hot air furnace heating service.	
								Percentage of heat units in fuel actually utilized based on tests.	Number heat units available in heated air.
Purchased as a commodity.		Anthracite coal	14,000 per lb.	$10.00 per ton	2,800,000	...		Coal furnace 20%	560,000
		Semi-anthracite coal	13,500 " "	$ 6.00 " "	4,500,000	...			900,000
		Bituminous coal	12,500 " "	$ 4.00 " "	6,250,000	...			1,250,000
		Crude oil	152,000 per gal.	3¢ per gal.	5,066,600	...		...	...
		Kerosene	124,000 " "	12¢ " "	1,033,000	Oil lamp	5,350	...	...
		Gasoline	118,000 " "	18¢ " "	655,500	Gasoline lamp	13,000	...	...
		Denatured alcohol	73,000 " "	40¢ " "	182,500	...		...	...
		Acetylene	1,400 per cu. ft.	4¢ lb. carbide	140,000	Acetylene burner	5,000	...	...
Purchased as a service.		Natural gas	1,000 " "	50¢ per 1,000 cu. ft.	2,000,000	Welsbach burner	26,400	Gas burner in Coal furnace 30% Gas furnace 62%	600,000 1,240,000
	Artificial gases.	Oil gas	640 " "	$1.00 " " "	640,000	Flat flame burner Welsbach burner	5,000 13,000	...	...
		Retort coal gas	640 " "	$1.00 " " "	640,000	Flat flame burner Welsbach burner	5,000 13,000	...	...
		Gasoline gas	625 " "	$1.00 " " "	625,000	Flat flame burner Welsbach burner	5,000 13,000	...	...
		Coke oven gas	600 " "	$1.00 " " "	600,000	Flat flame burner Welsbach burner	5,000 13,000	...	...
		Carbureted water gas	600 " "	$1.00 " " "	600,000	Flat flame burner Welsbach burner	5,000 13,000	...	...
		Electricity	3,412 per kw.	5¢ per kw. hr.	68,200	Carbon lamp Tungsten lamp	6,000 16,000	...	...

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